Fermi National Accelerator Laboratory

TM-1495

Simulation of Bunches Coalesing in the Main Ring, in the Presence of a High-Frequency, Wide-Band Resonator

R. Garoby
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

December 4, 1986

TM-1495
0439.030

SIMULATION OF BUNCHES COALESING IN THE MAIN RING, IN THE PRESENCE OF A HIGH-FREQUENCY, WIDE-BAND RESONATOR

R. Garoby

December 4, 1986

INTRODUCTION

During the first part of the coalescing process, bunches are being stretched until they fill the ≃1 kV @ 53 MHz bucket.

Applying the "Keil-Schnell-Boussard" criteria (see Appendix A) for microwave instability inside that bunch gives:

$$|Z/n| \leq 5.6\ \Omega \text{ for } N_b = 10^{10} \text{ ppb} .$$

It is very likely that local instabilities develop inside the bunch during the manipulation. The computer program ESME was run under these conditions to give an approximate picture of the bunch distortions. Outputs are presented here.

Since microwave signals had been observed during the second part of coalescing (bunch rotation), some simulations have been done at that part. No catastrophic degradation showed up with the model used, as the computer outputs indicate.

THE MODEL

The high frequency impedance seen by the beam was simulated by a Q=1 resonator at 2000 MHz. Two "reasonable" impedance values were tested.

Z (@ 2000 MHz) = 800 kΩ equivalent to $|Z/n|$ = 19 Ω and
Z (@ 2000 MHz) = 600 kΩ equivalent to $|Z/n|$ = 9.5 Ω.

Care was taken that the program was giving meaningful results. That was checked by comparing the voltage due to the resonator, along the bunch, as computed by ESME, with the one given by approximate formulas (@ CERN 77-10, p. 95). Unfortunately such a formula can only be used when the bunch shape is smooth, so only the initial state has been analyzed. A satisfying set of parameters is: 10,000 macroparticles into 32 FFT bins, for debunching analysis. CPU time is already greater than four hours in the FPS 164 in these conditions.

For bunch rotation analysis, the number of FFT bins was brought up to 256. It was necessary, since bunch length varies drastically. Ten thousand (10,000) macro-particles were also used. Reliability of the results is probably less good than for debunching. But since little bunch distortions are detected up to $N_b = 2\times10^{11}$ ppb (2x design value), one can safely consider that an upper limit of the bunch degradation is obtained.

DEBUNCHING SIMULATIONS RESULTS

Figures 1.1, 1.2, and 1.3 show the voltage program used, together with bucket height and ν_s. The table below indicates the parameters used in the simulation together with the relevant output pictures.

$\|Z/n\|$	0.1 Ω	9.5 Ω	19 Ω	19 Ω	19 Ω
N_b		8×10^{10} ppb	5×10^{9}	10^{10}	2×10^{10}
Figures	2.1 to 2.8	3.1 to 3.8	4	5	6.1 to 6.8

Figure 4 shows the present operational situation (at least if one guesses $|Z/n| = 19$ Ω!).

The result is already different from the zero intensity one (Fig. 2.6). Bunch distortion is not excessive, but energy spread is obviously greater by 2 or 3 MeV. This could explain the need to go to a higher voltage during bunch rotation (33 kV @ h = 53 raised to 44 kV) since bunch rotation basically exchanges energy spread for bunch length.

The situation at $N_b = 10^{10}$ ppb with $|Z/n| = 19$ Ω is very bad (Fig. 5), and at $N_b = 2\times10^{10}$ ppb (Fig. 6.6) it is hard to describe.

If one guesses $|Z/n| = 9.5$ Ω, the result (Fig. 3.6) is comparable to $|Z/n| = 1$ Ω (Fig. 5) but at two times the intensity.

BUNCH ROTATION RESULTS

Because of program capabilities the simulation was run on a single-bunch with $\epsilon_\ell = 2$ eV-sec, initialy matched to a 200 V h = 53 bucket. That was supposed to be an approximation of the chain of 10 adjacent bunches. RF parameters during rotation are the ones previously used by D. Wildman:

$$\hat{V}(h = 53) = 44 \text{ kV}$$

$$\hat{V}(h = 106) = 7.5 \text{ kV}.$$

The low intensity limit is described in Figs. 7.1, 7.2, and 7.3.

Computations have been done for $|Z/n| = 19$ Ω and $N_b = 2\times10^{11}$ ppb (2x design value). Outputs are shown in Fig. 8.1, 8.2, and 8.3.

The following table summarizes the comparison of some relevant numbers in both cases.

	N_b = 0 ppb	N_b = 2×10^{11} ppb
Optimum rotation time	3651 turns	3708 turns
RMS spread in azimuth	7.96×10^{-4} rad	9.64×10^{-4} rad
RMS energy spread	39.7 MeV	34.3 MeV

So the minimum length is observed later (57 turns or more than 1 nsec) and bunch length is increased by ≃20%. Computation at $N_b = 10^{11}$ ppb indicate only an increase of ≃6%. No noticeable bunch distortions show up.

This part of the process is much less sensitive to the microwave wide-band resonator than the first one.

CONCLUSIONS

With due regard to the crude models used for the computations, one can nevertheless estimate that:

1. The first part of the coalescing process is very sensitive to the machine impedance. Great difficulties are likely to appear when going to the design intensity, or slightly higher.

2. The bunch rotation is much more tolerant, but some decrease in performance can be suspected, with a threshold around the design intensity ($N_b = 10^{11}$ ppp).

The obvious recommendations that one can make from that basis are:

1. Measure machine impedance and try to reduce it.

2. Modify the first part of the coalescing process to make it less impedance sensitive. One possibility for that is to go to a more adiabatic bunch lengthening technique, which will provide a stretched bunch in a much shorter amount of time.

APPENDIX A

CALCULATION OF THE THRESHOLD FOR MICROWAVE INSTABILITY

Formula:

$$\left|\frac{Z}{n}\right| \leq F \left(\frac{E_o}{e}\right)\left(\frac{\eta}{\gamma}\right) \left(\frac{[\Delta\beta\gamma]^2_{1/2\text{height}}}{\hat{I}}\right)$$

(@ CERN 77-13, p. 178)

$F = 0.65$

$\frac{E_o}{e} = 938.856$ MeV

$\gamma = 160$ $\quad$ ($E_{total} = 150$ GeV)

$|\eta| = 2.81 \times 10^{-3}$

If one debunches completely a bunch of emittances ϵ_ℓ, the approximate relation between bunch length ℓ_b (1 rf wavelength) and bunch half-energy spread $\Delta\hat{E}_b$ is:

$$\pi \times \Delta\hat{E}_b \times \frac{\ell_b}{2} = \epsilon \ .$$

Application

$\epsilon_\ell = 0.16$eVs $\ell_b = 18.8$ ns $\Rightarrow \Delta E_b = 5.42$ MeV.
Assuming a parabolic distribution in the center of the bunch, the full energy spread at half-height is

$$(\Delta E)_{1/2 \text{ height}} = \left(\frac{1}{\sqrt{2}}\right) \times 2 \times \Delta\hat{E}_b = 7.66 \text{ MeV}$$

so $$(\Delta\beta\gamma)_{1/2 \text{ height}} \simeq (\Delta\gamma)_{1/2 \text{ height}} = \frac{(\Delta E)_{1/2 \text{ height}}}{E_o} = 8.17 \times 10^{-3}$$

The mean beam current along the bunch length is:

$$I_o = \frac{Nec}{\ell_b}$$

and the instantaneous current in the center of the bunch is:

$$\hat{I} = \frac{3}{2} I_o$$

Application: $N = 10^{10}$ ppb (@ Design Report Tevatron 1)

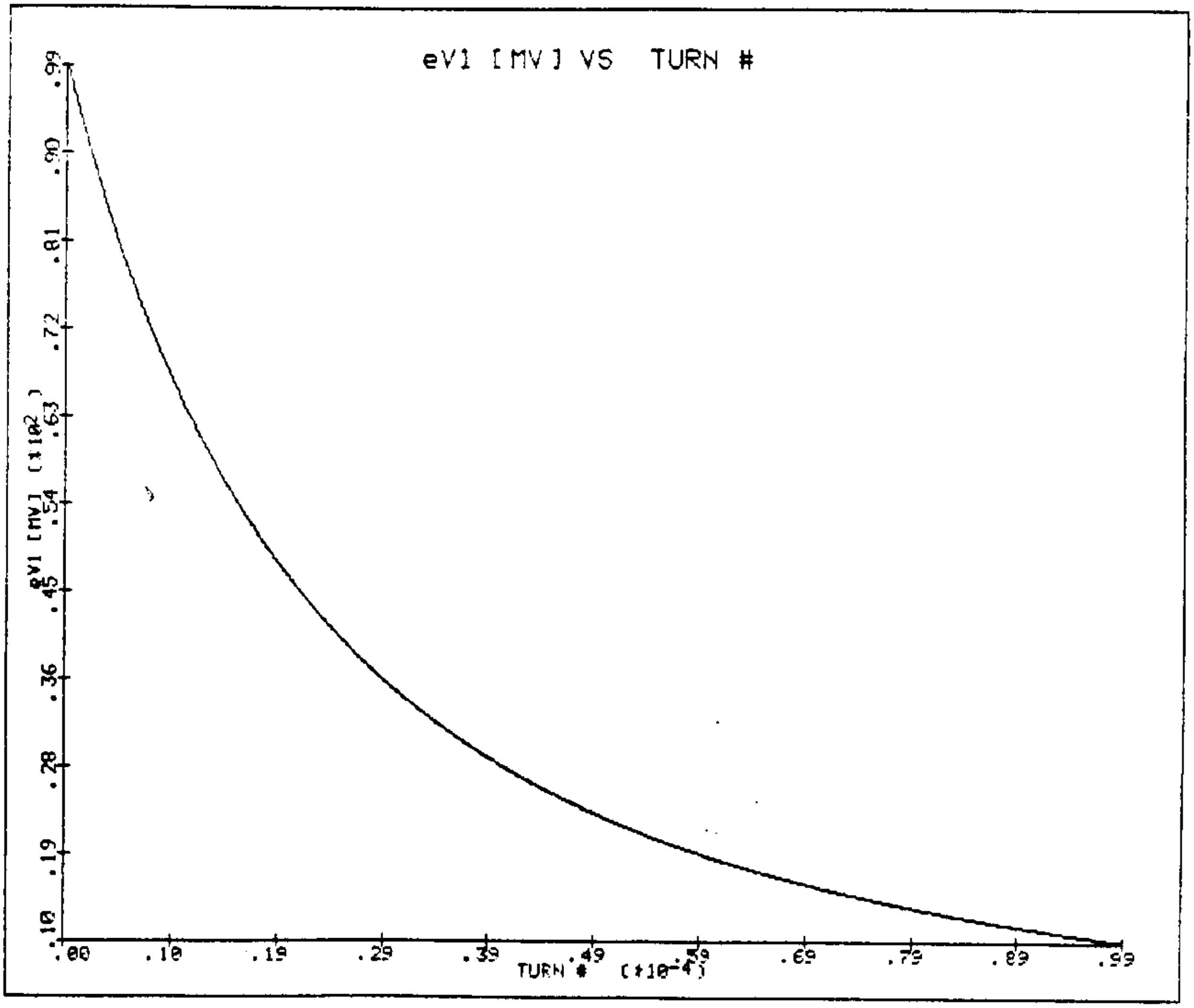
So $\hat{I} = 0.128$ A.

Consequently $\quad \left|\frac{Z}{n}\right| \leq 5.6\ \Omega$

Editor's Note

This document has been created from a private note written by R. Garoby during his visit to Fermilab. Therefore, the author is not responsible for any errors or omissions since he never intended such a wide audience for this piece of research.

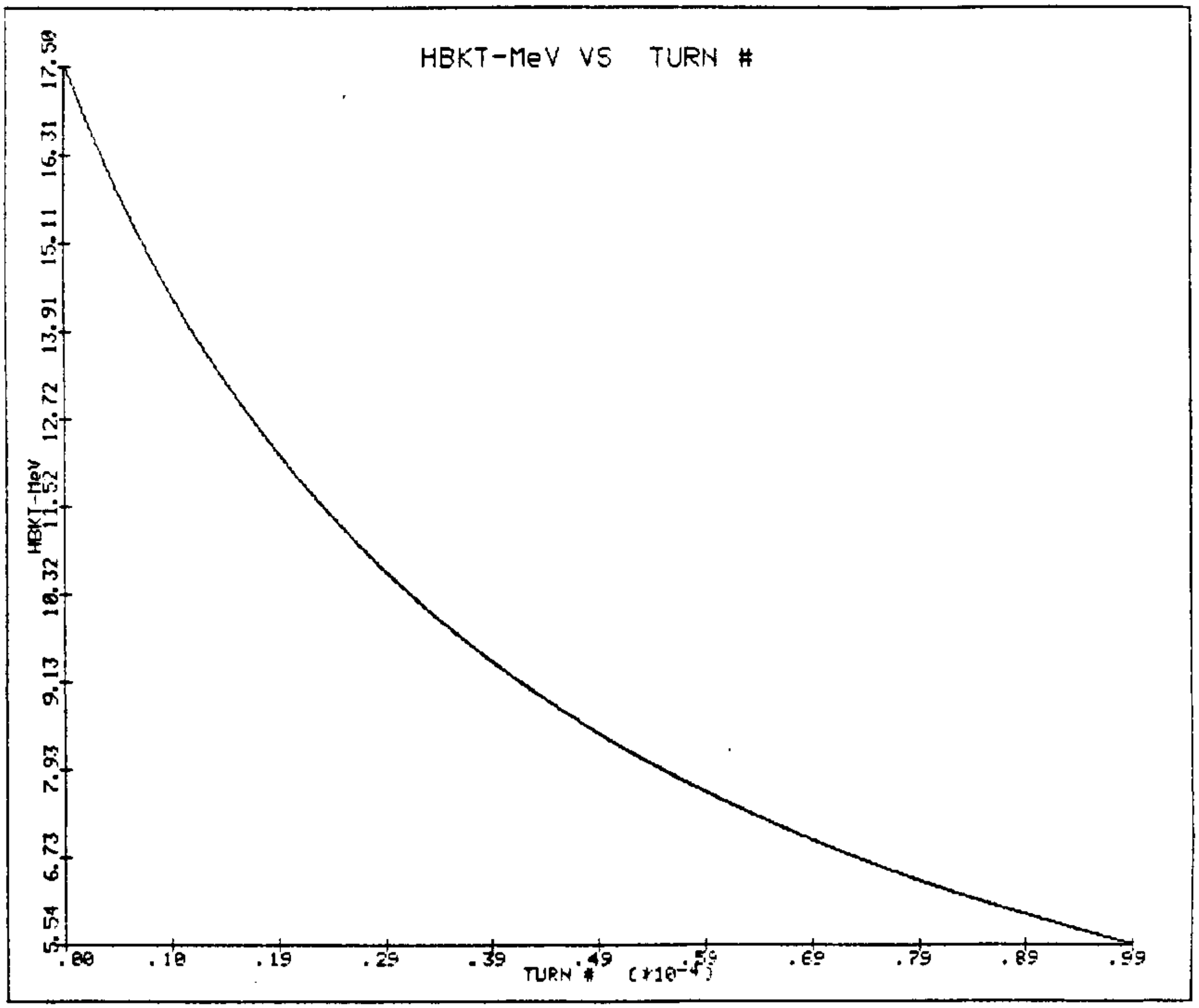
Figure 1.1



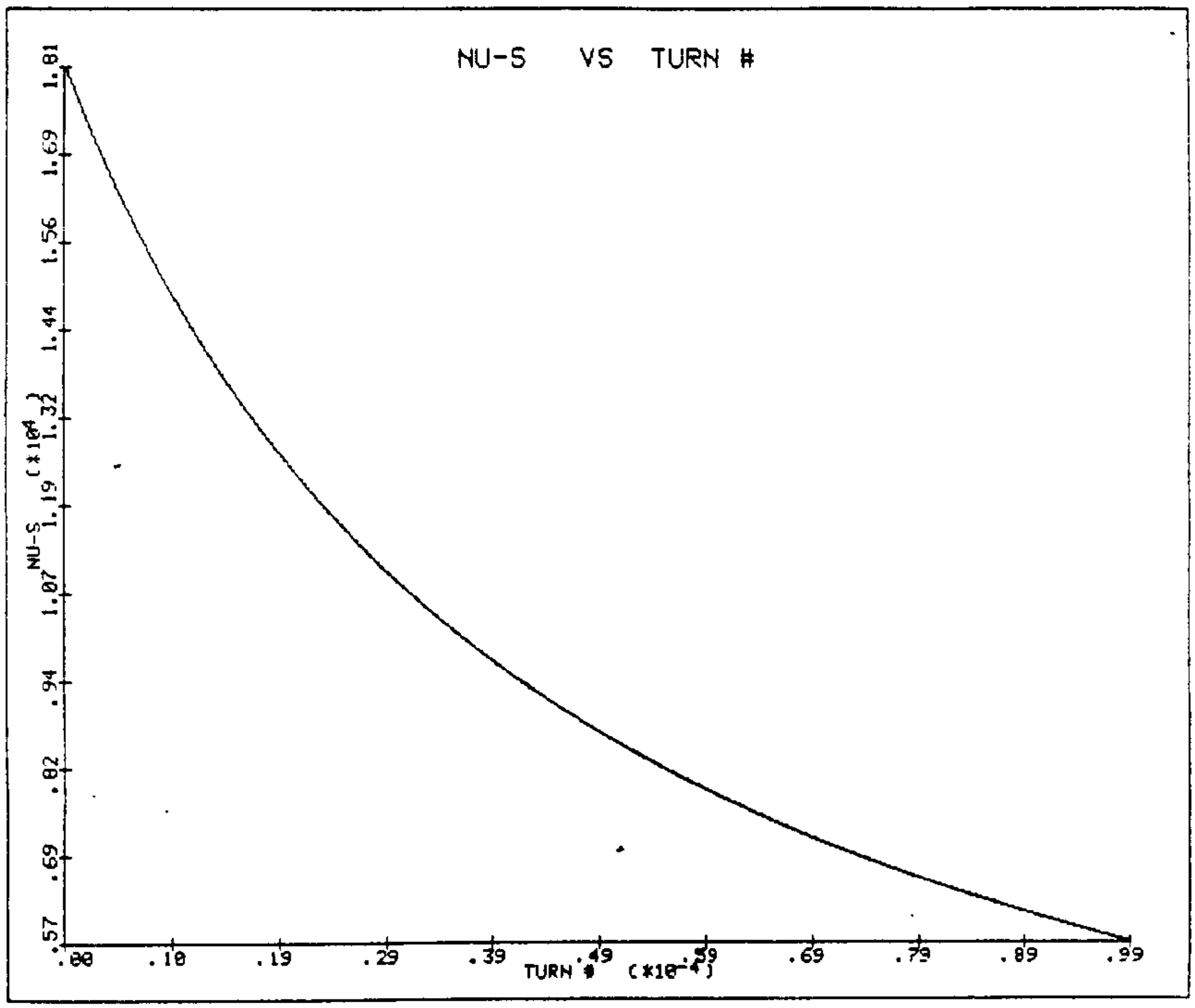
eV1 [MV] VS TURN #
eV1 [MV] (*10^2)
.10
.19
.28
.36
.45
.54
.63
.72
.81
.90
.99
.00
.10
.19
.29
.39
.49
.59
.69
.79
.89
.99
TURN # (*10^-4)

1.1

1:2.


HBKT-MeV VS TURN #
HBKT-MeV
17.50
16.31
15.11
13.91
12.72
11.52
10.32
9.13
7.93
6.73
5.54
.00
.10
.19
.29
.39
.49
.59
.69
.79
.89
.99
TURN #

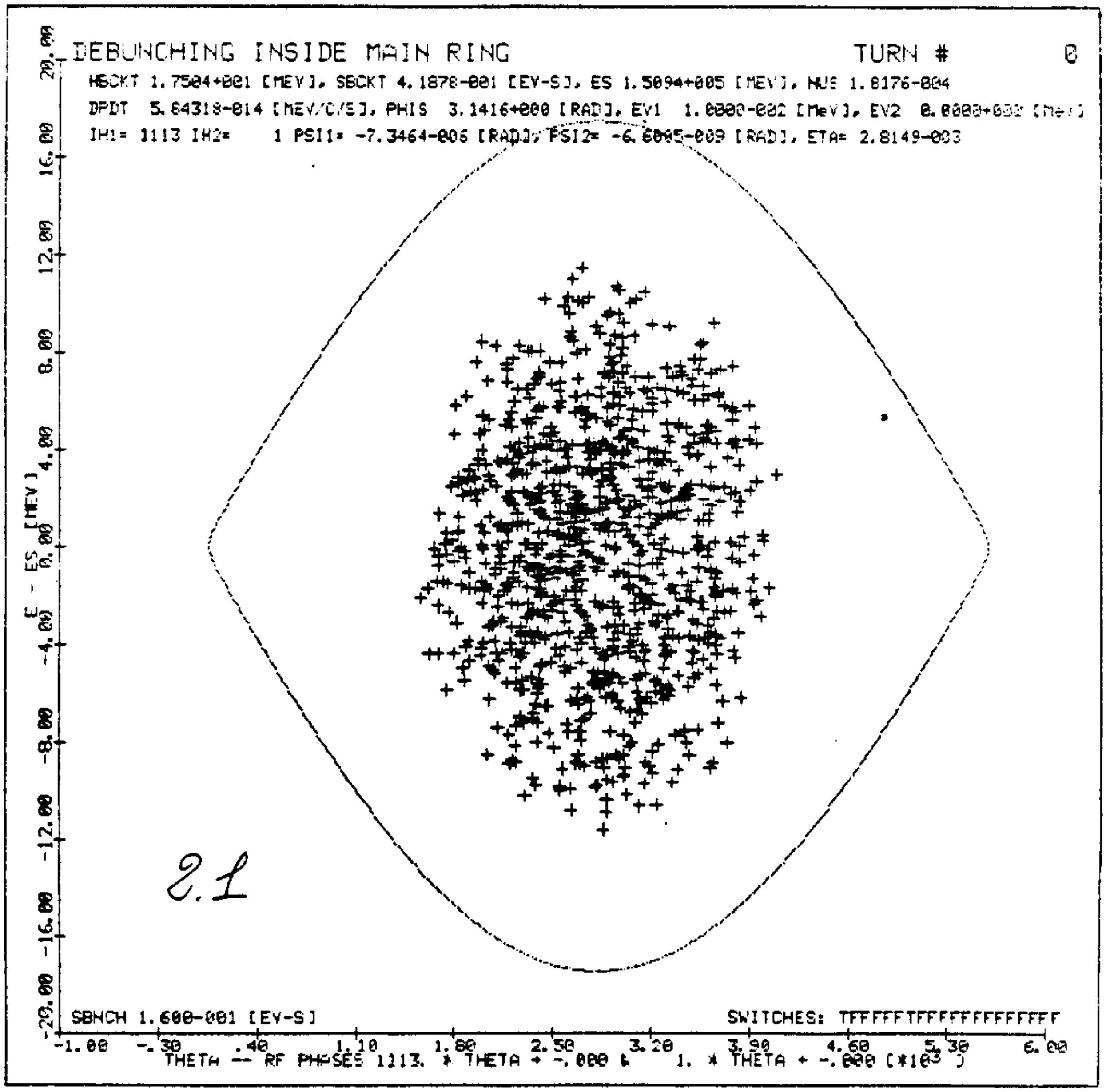
1. 2

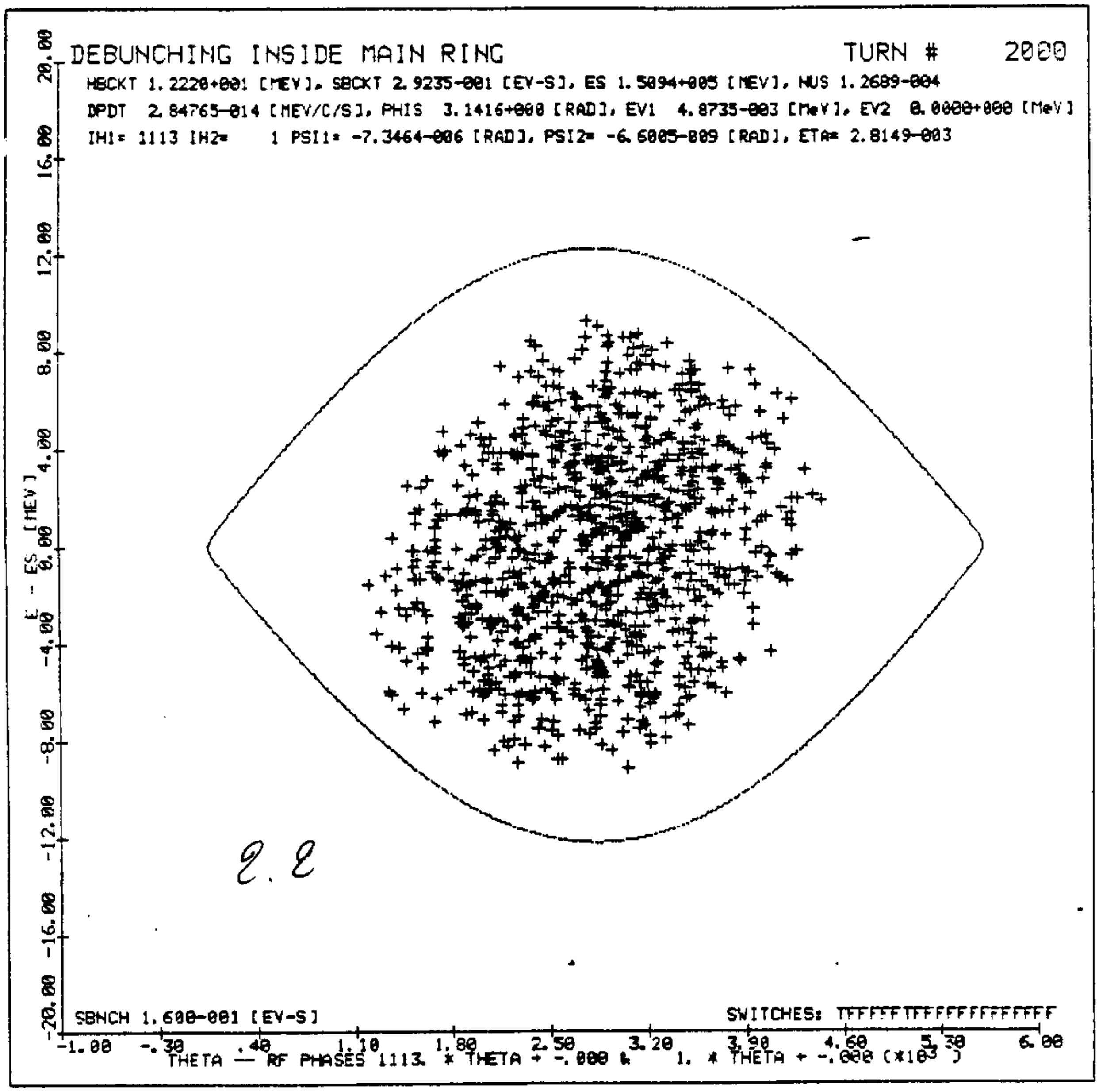


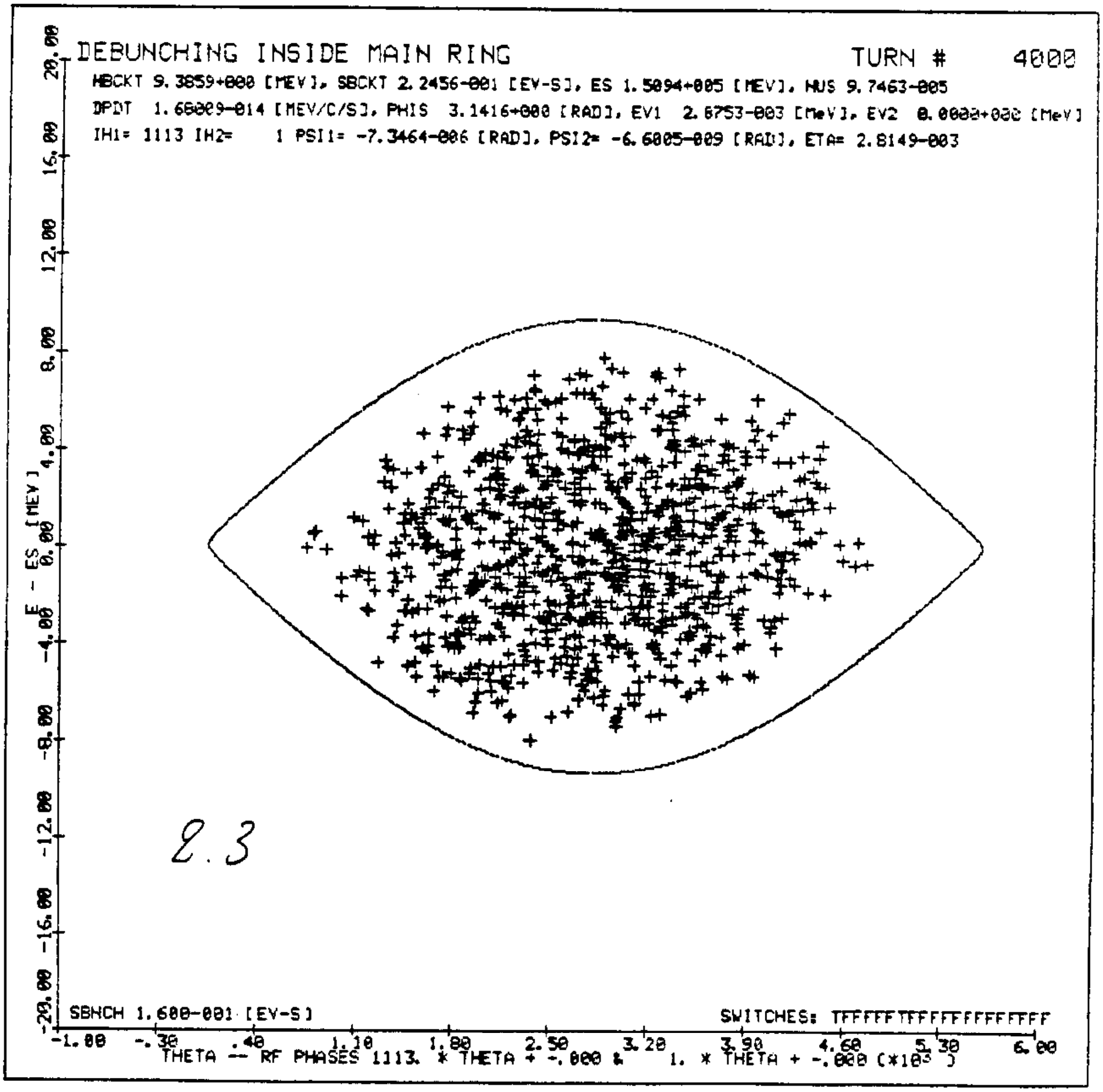
NU-S VS TURN #
1.81
1.69
1.56
1.44
1.32
1.19
1.07
.94
.82
.69
.57
NU-S (*10^4)
.00
.10
.19
.29
.39
.49
.59
.69
.79
.89
.99
TURN # (*10^-4)

1.3

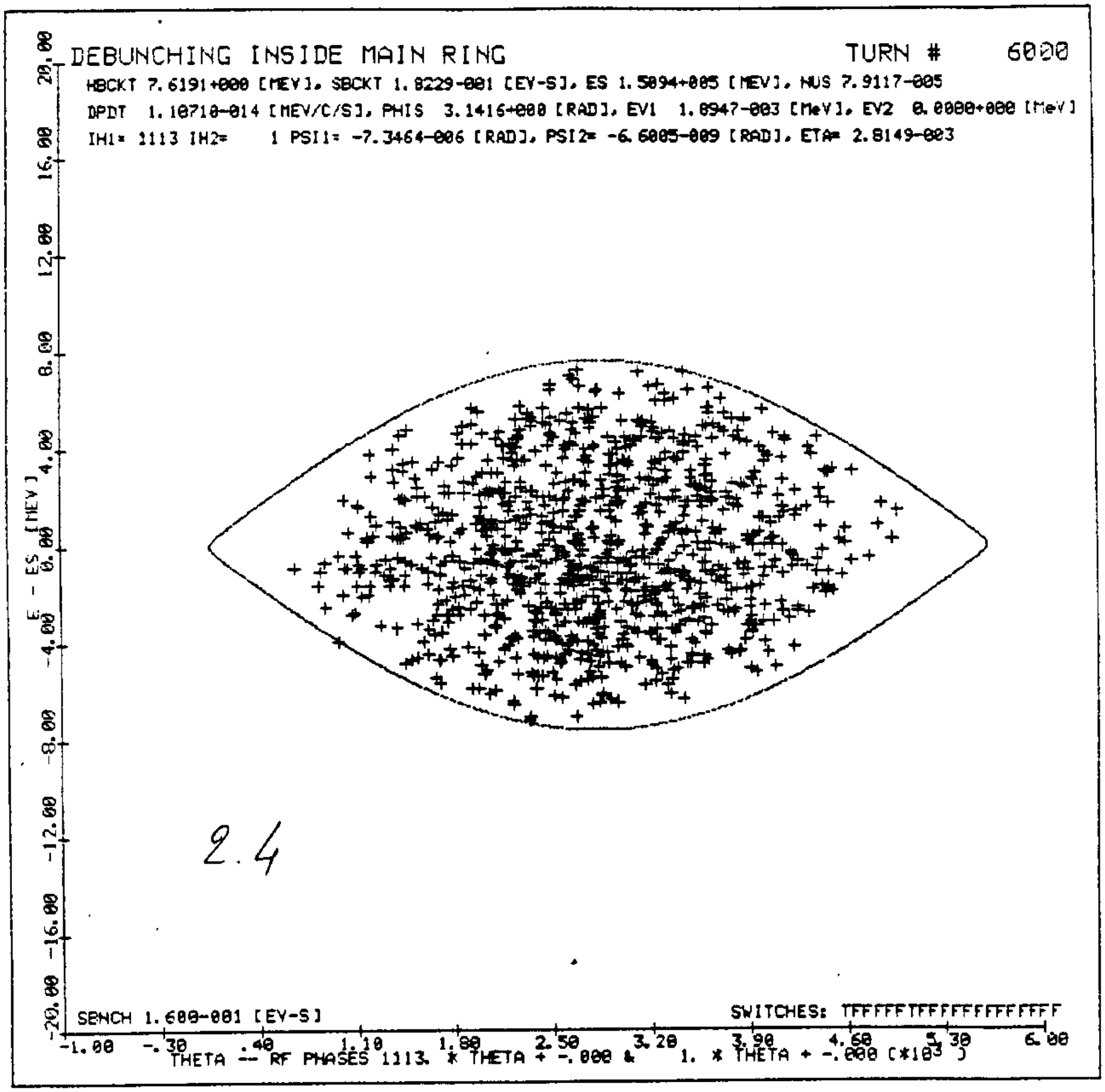
$\frac{Z}{n} = 0\Omega$

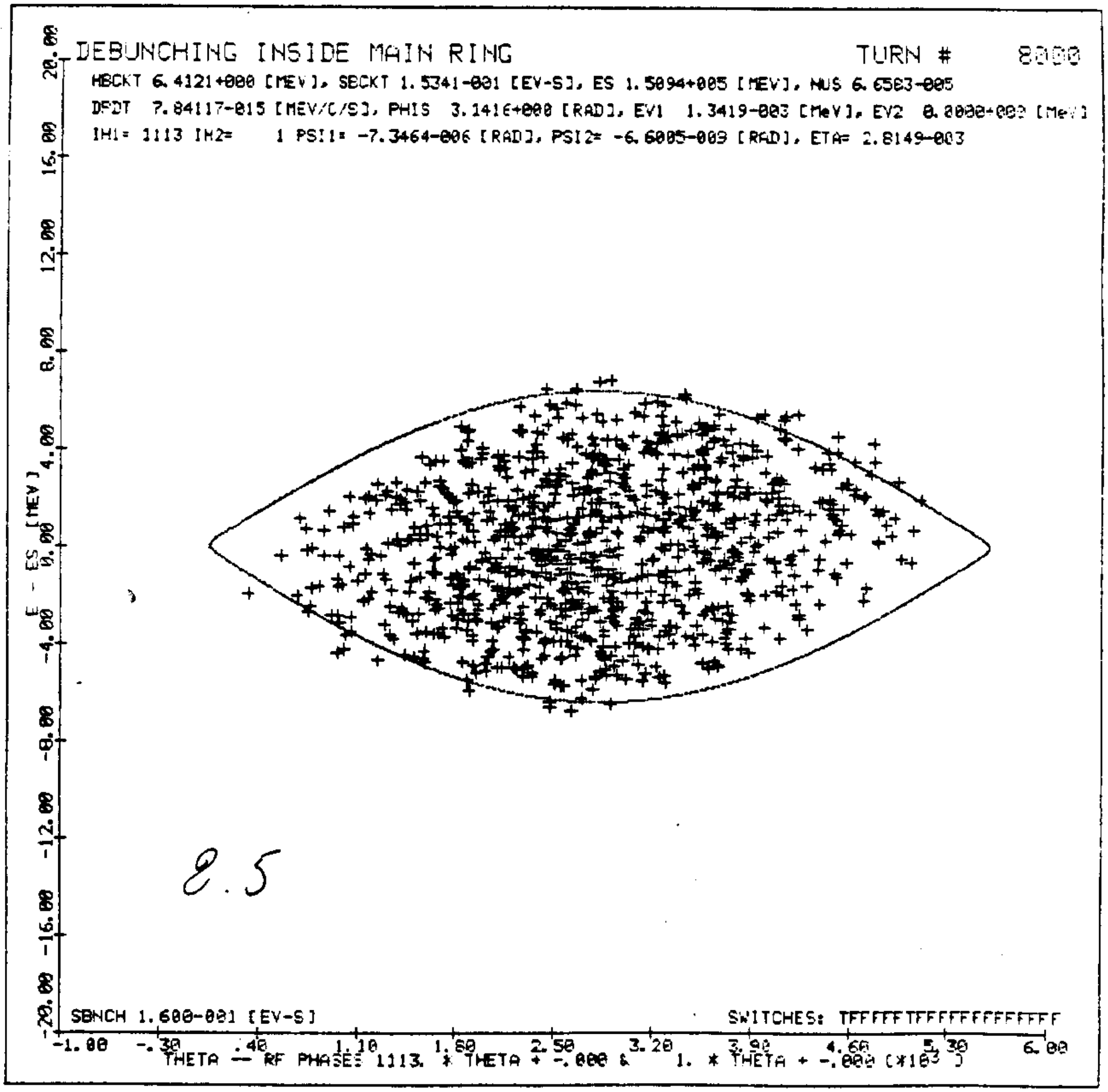



DEBUNCHING INSIDE MAIN RING
TURN # 2000
HBCKT 1.2220+001 [MEV], SBCKT 2.9235-001 [EV-S], ES 1.5094+005 [MEV], NUS 1.2689-004
DPDT 2.84765-014 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 4.8735-003 [MeV], EV2 0.0000+000 [MeV]
IH1= 1113 IH2= 1 PSI1= -7.3464-006 [RAD], PSI2= -6.6005-009 [RAD], ETA= 2.8149-003
E - ES [MEV]
20.00
16.00
12.00
8.00
4.00
0.00
-4.00
-8.00
-12.00
-16.00
-20.00
2.2
SBNCH 1.600-001 [EV-S]
SWITCHES: TFFFFTFFFFFFFFFFFFFF
-1.00
-.30
.40
1.10
1.80
2.50
3.20
3.90
4.60
5.30
6.00
THETA — RF PHASES 1113. * THETA + -.000 & 1. * THETA + -.000 (*10^3)

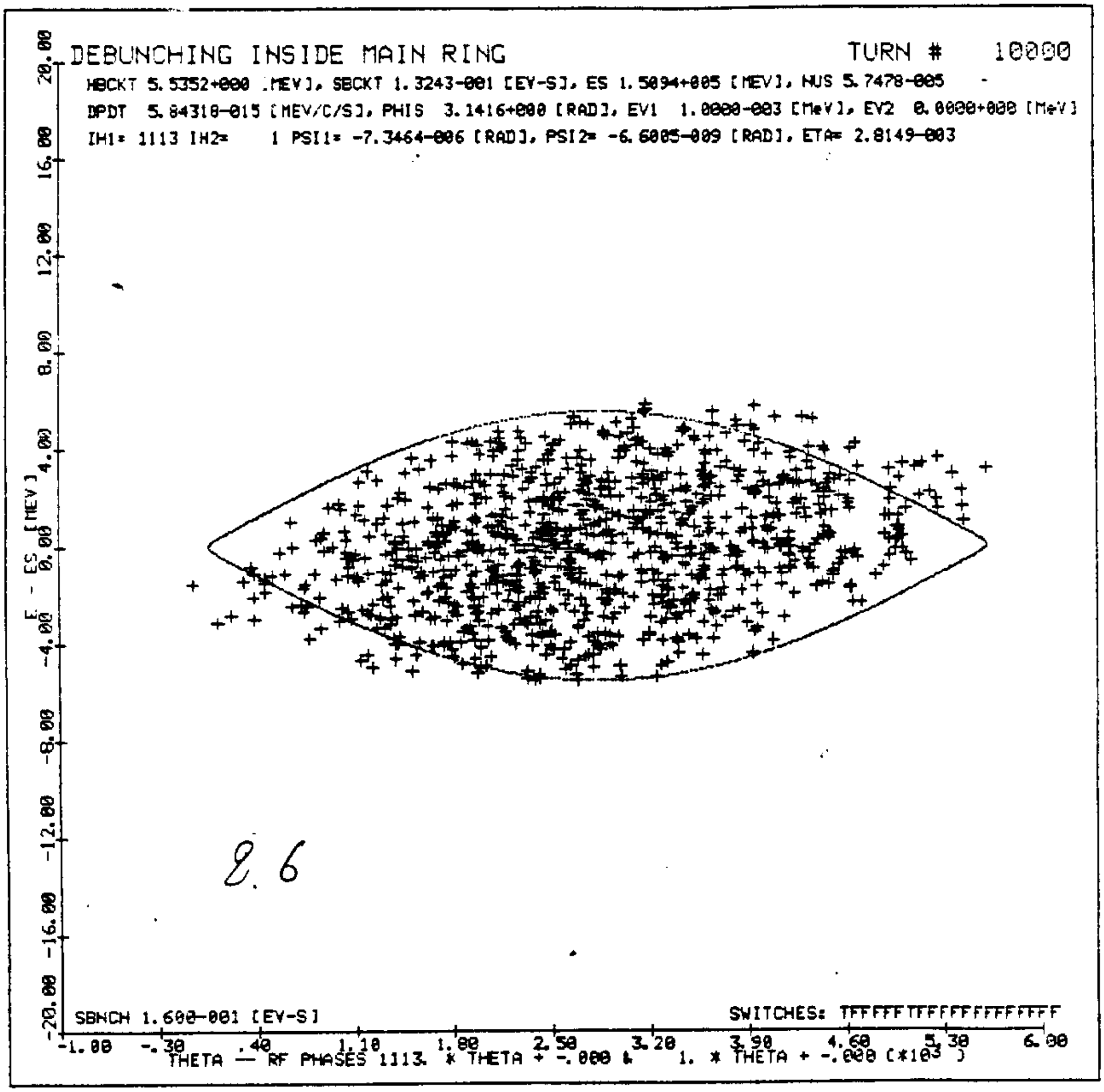


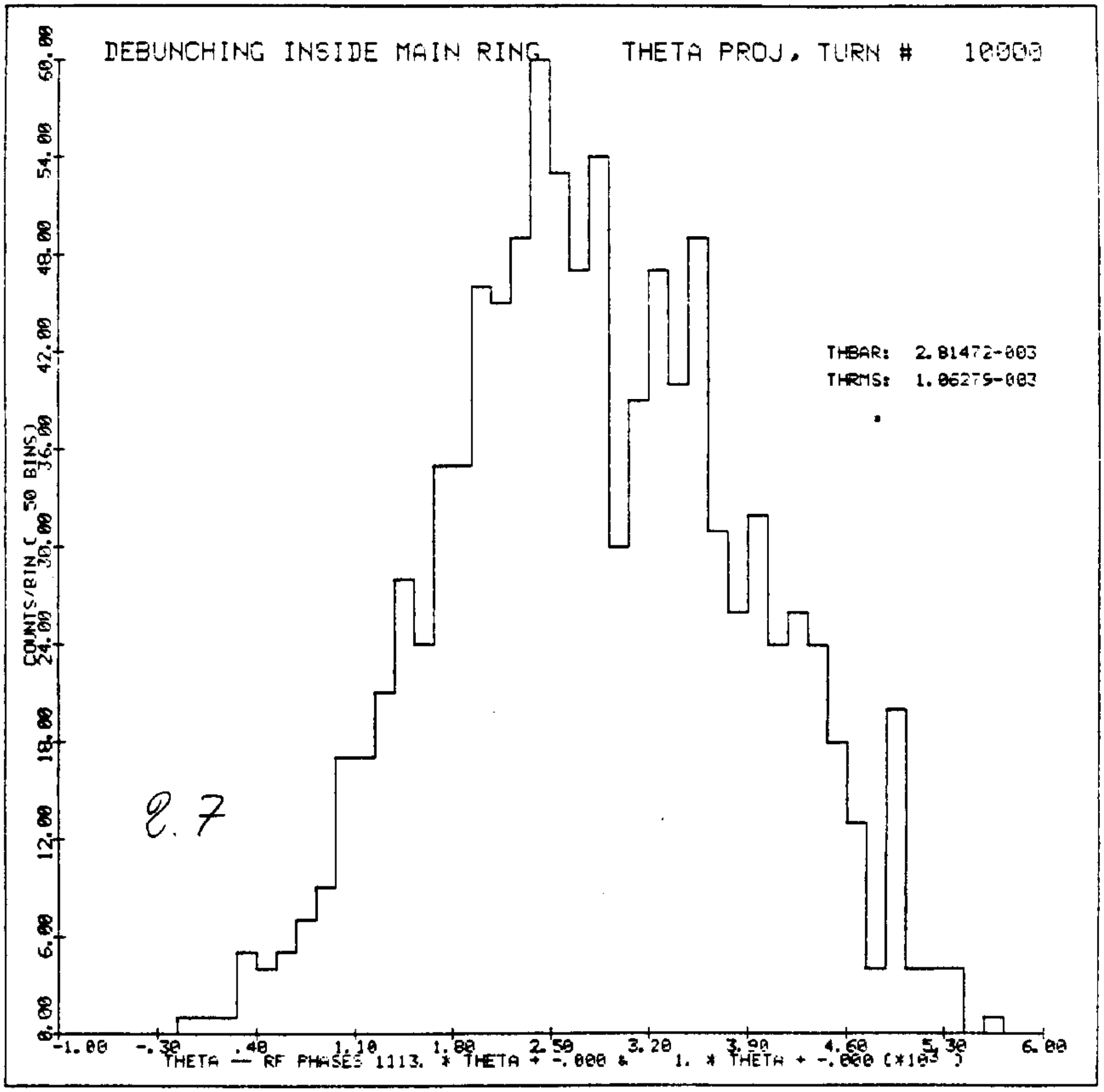
DEBUNCHING INSIDE MAIN RING
TURN # 4000
HBCKT 9.3859+000 [MEV], SBCKT 2.2456-001 [EV-S], ES 1.5094+005 [MEV], NUS 9.7463-005
DPDT 1.68009-014 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 2.6753-003 [MeV], EV2 0.0000+000 [MeV]
IH1= 1113 IH2= 1 PSI1= -7.3464-006 [RAD], PSI2= -6.6005-009 [RAD], ETA= 2.8149-003
E - ES [MEV]
20.00
16.00
12.00
8.00
4.00
0.00
-4.00
-8.00
-12.00
-16.00
-20.00
2.3
SBNCH 1.600-001 [EV-S]
SWITCHES: TFFFFFTFFFFFFFFFFFFF
-1.00
-.30
.40
1.10
1.80
2.50
3.20
3.90
4.60
5.30
6.00
THETA -- RF PHASES 1113. * THETA + -.000 & 1. * THETA + -.000 (*10^3)

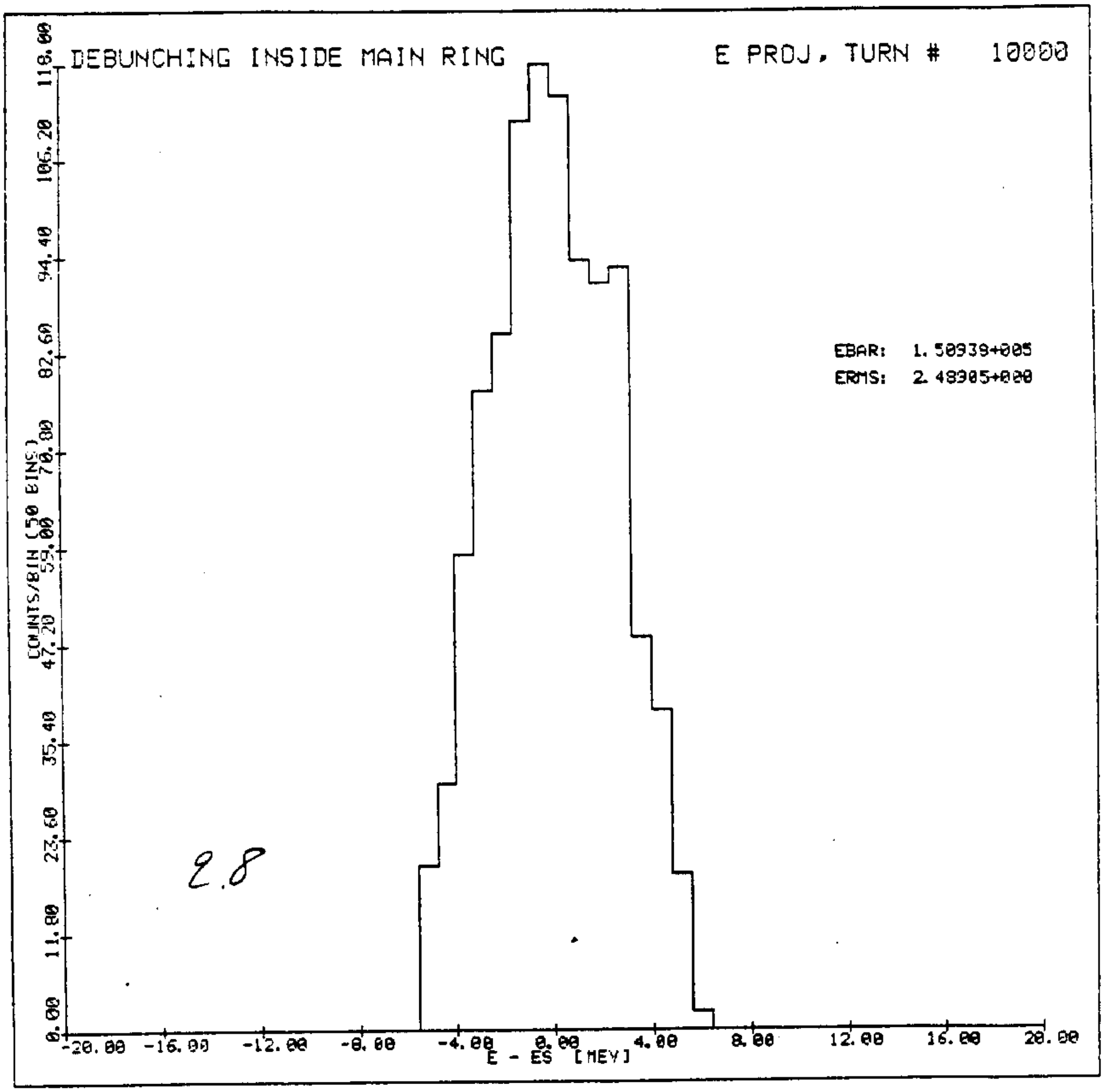

DEBUNCHING INSIDE MAIN RING
TURN # 6000
HBCKT 7.6191+000 [MEV], SBCKT 1.8229-001 [EV-S], ES 1.5094+005 [MEV], NUS 7.9117-005
DPDT 1.10718-014 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 1.0947-003 [MeV], EV2 0.0000+000 [MeV]
IH1= 1113 IH2= 1 PSI1= -7.3464-006 [RAD], PSI2= -6.6005-009 [RAD], ETA= 2.8149-003
E - ES [MEV]
20.00
16.00
12.00
8.00
4.00
0.00
-4.00
-8.00
-12.00
-16.00
-20.00
2.4
SENCH 1.600-001 [EV-S]
SWITCHES: TFFFFFTFFFFFFFFFFFFF
-1.00
-.30
.40
1.10
1.80
2.50
3.20
3.90
4.60
5.30
6.00
THETA -- RF PHASES 1113. * THETA + -.000 & 1. * THETA + -.000 [*10^3]


DEBUNCHING INSIDE MAIN RING
TURN # 8000
HBCKT 6.4121+000 [MEV], SBCKT 1.5341-001 [EV-S], ES 1.5094+005 [MEV], NUS 6.6583-005
DFDT 7.84117-015 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 1.3419-003 [MeV], EV2 0.0000+000 [MeV]
IH1= 1113 IH2= 1 PSI1= -7.3464-006 [RAD], PSI2= -6.6005-009 [RAD], ETA= 2.8149-003
E - ES [MEV]
20.00
16.00
12.00
8.00
4.00
0.00
-4.00
-8.00
-12.00
-16.00
-20.00
SBNCH 1.600-001 [EV-S]
SWITCHES: TFFFFFTFFFFFFFFFFFFF
-1.00
-.30
.40
1.10
1.80
2.50
3.20
3.90
4.60
5.30
6.00
THETA -- RF PHASES 1113. * THETA + -.000 & 1. * THETA + -.000 (*10^3)

8.5


DEBUNCHING INSIDE MAIN RING
TURN # 10000
HBCKT 5.5352+000 [MEV], SBCKT 1.3243-001 [EV-S], ES 1.5094+005 [MEV], NUS 5.7478-005
DPDT 5.84318-015 [MEV/C/S], PHIS 3.1416+000 [RAD], EV1 1.0000-003 [MeV], EV2 0.0000+000 [MeV]
IH1= 1113 IH2= 1 PSI1= -7.3464-006 [RAD], PSI2= -6.6005-009 [RAD], ETA= 2.8149-003
E - ES [MEV]
20.00
16.00
12.00
8.00
4.00
0.00
-4.00
-8.00
-12.00
-16.00
-20.00
8.6
SBNCH 1.600-001 [EV-S]
SWITCHES: TFFFFFTFFFFFFFFFFFFF
-1.00
-.30
.40
1.10
1.80
2.50
3.20
3.90
4.60
5.30
6.00
THETA — RF PHASES 1113. * THETA + -.000 & 1. * THETA + -.000 (*10^3)

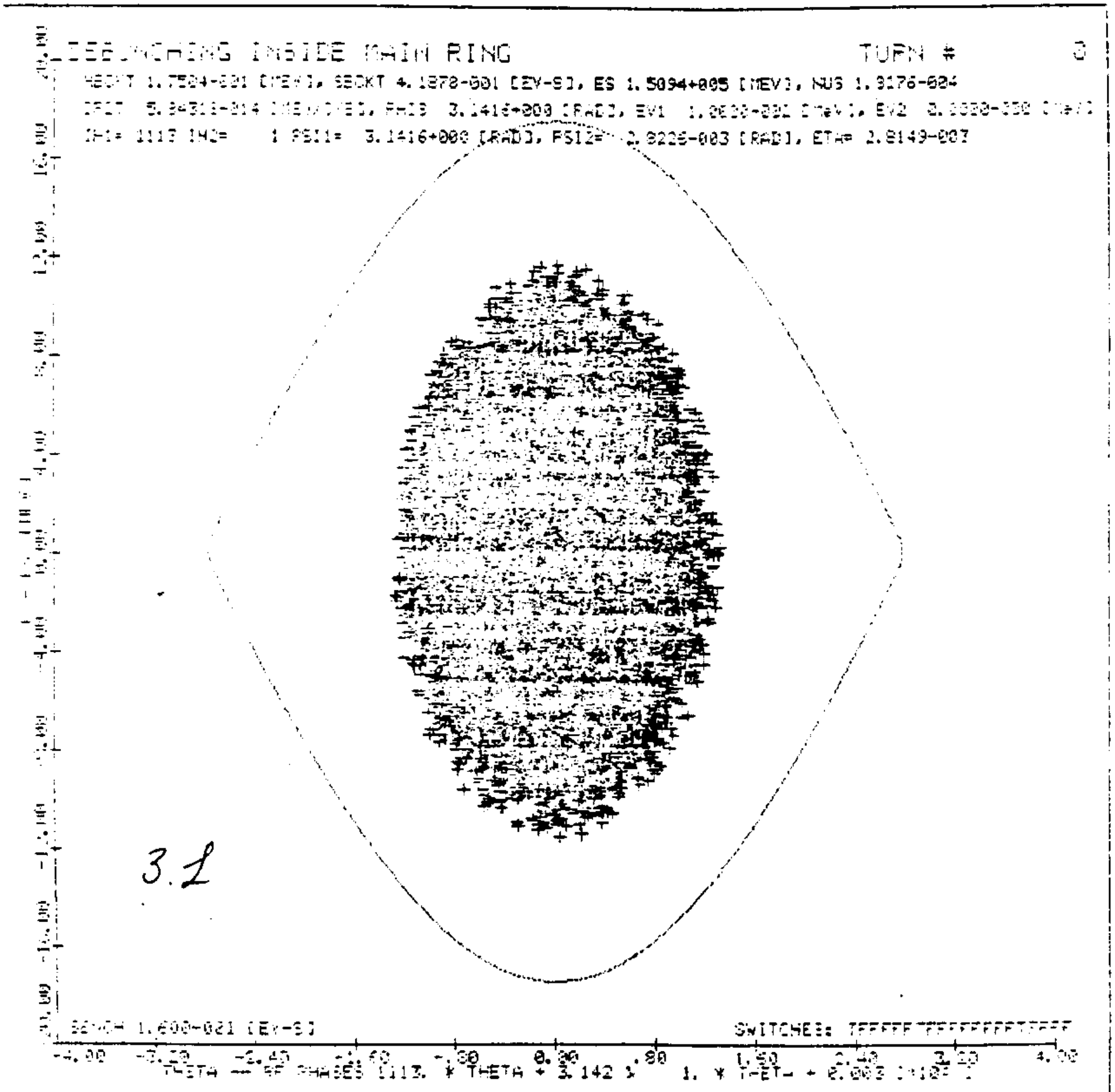

DEBUNCHING INSIDE MAIN RING THETA PROJ, TURN # 10000
COUNTS/BIN (50 BINS)
60.00
54.00
48.00
42.00
36.00
30.00
24.00
18.00
12.00
6.00
0.00
-1.00
-.30
.40
1.10
1.80
2.50
3.20
3.90
4.60
5.30
6.00
THETA — RF PHASES 1113. * THETA + -.000 & 1. * THETA + -.000 (*10^-3)
THBAR: 2.81472-003
THRMS: 1.06275-003
2.7

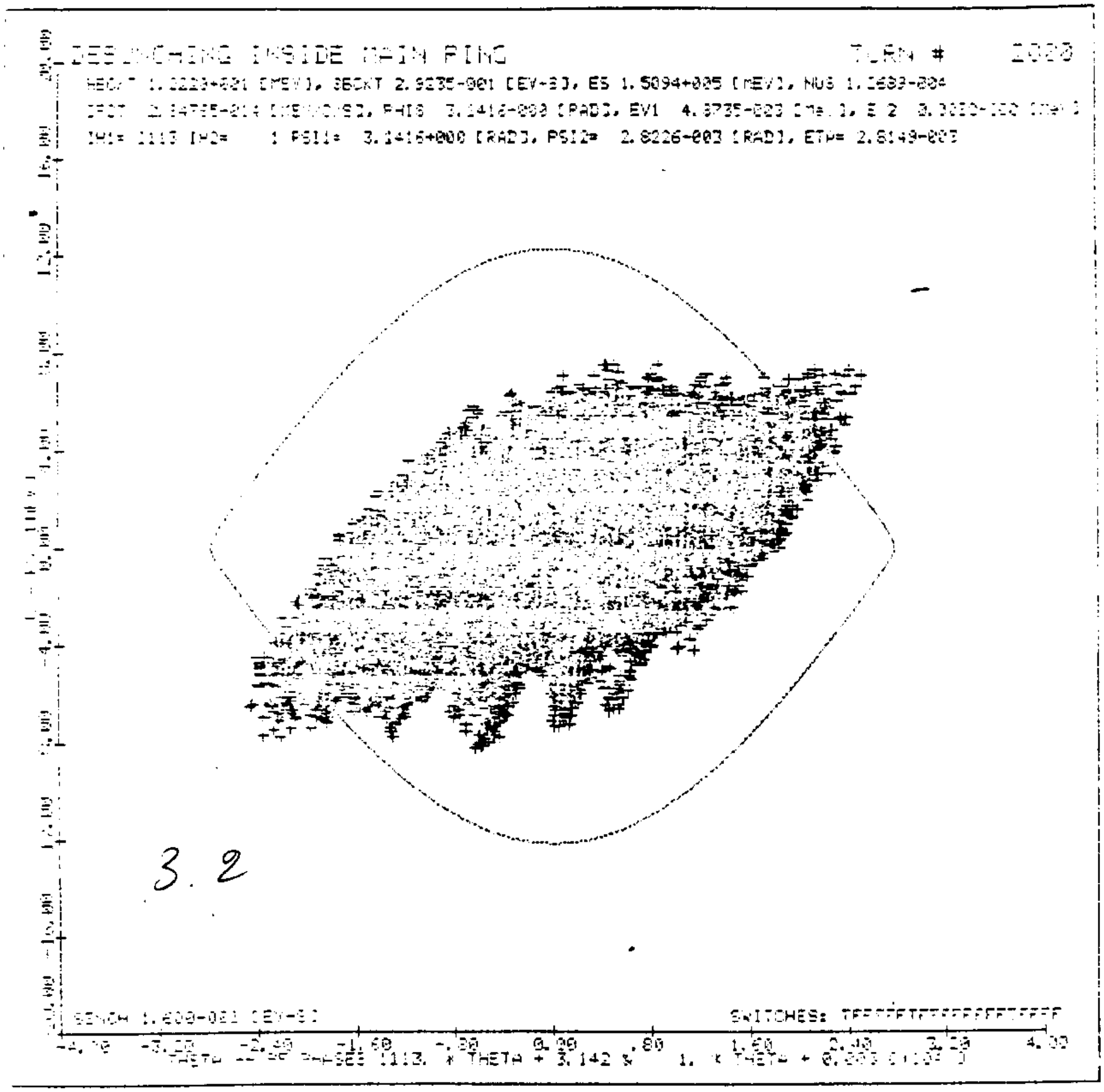

DEBUNCHING INSIDE MAIN RING
E PROJ, TURN # 10000
EBAR: 1.50939+005
ERMS: 2.48305+000
COUNTS/BIN (50 BINS)
118.00
106.20
94.40
82.60
70.80
59.00
47.20
35.40
23.60
11.80
0.00
-20.00
-16.00
-12.00
-8.00
-4.00
0.00
4.00
8.00
12.00
16.00
20.00
E - ES [MEV]
2.8

Wide band monator $\left\{ \begin{array}{l} f_R = 2000\ MHz \\ Z(@ f_R) = 400\ k\Omega \end{array} \right.$

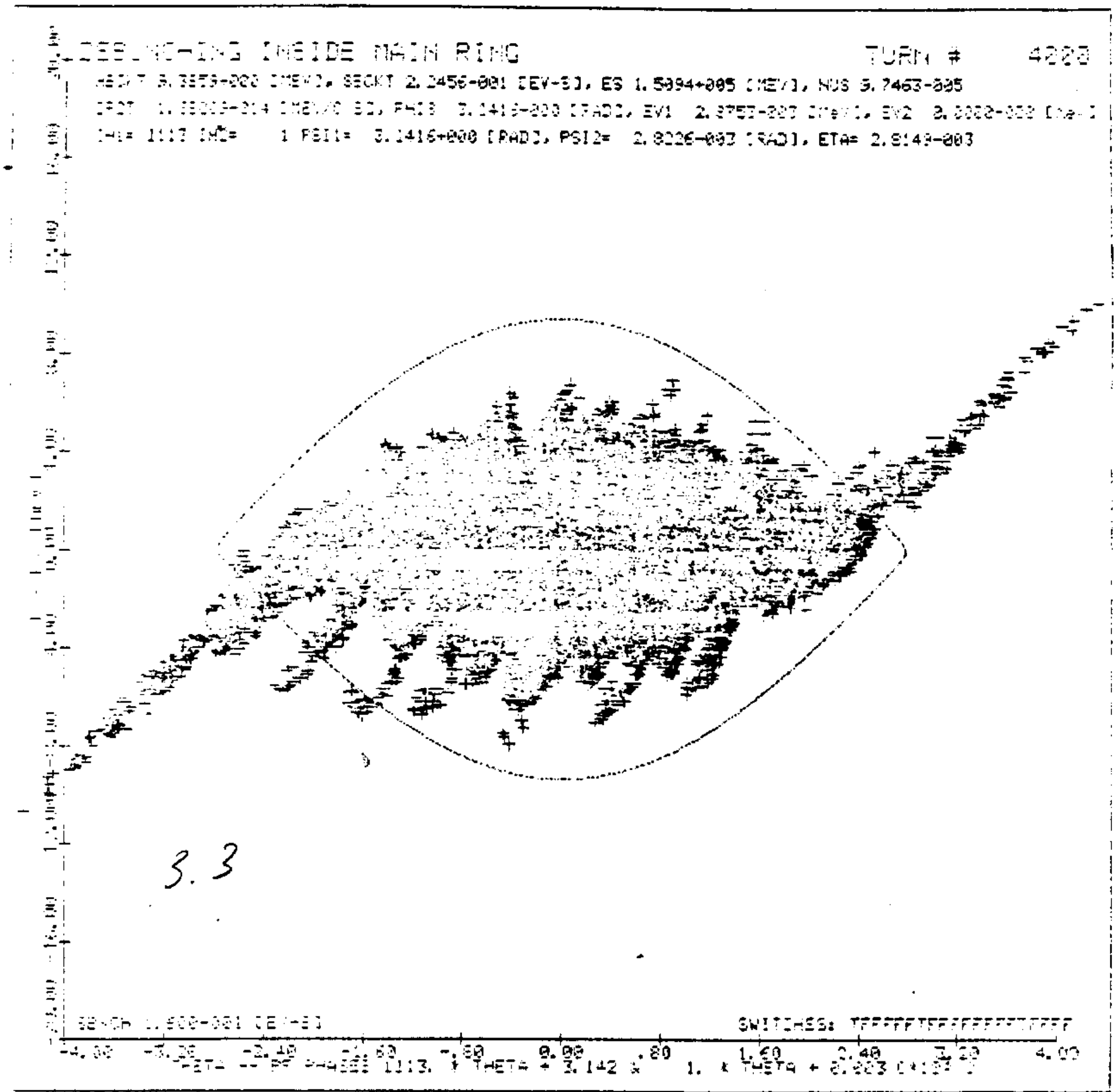
$\Rightarrow \frac{Z}{n} = 3.5\ \Omega$

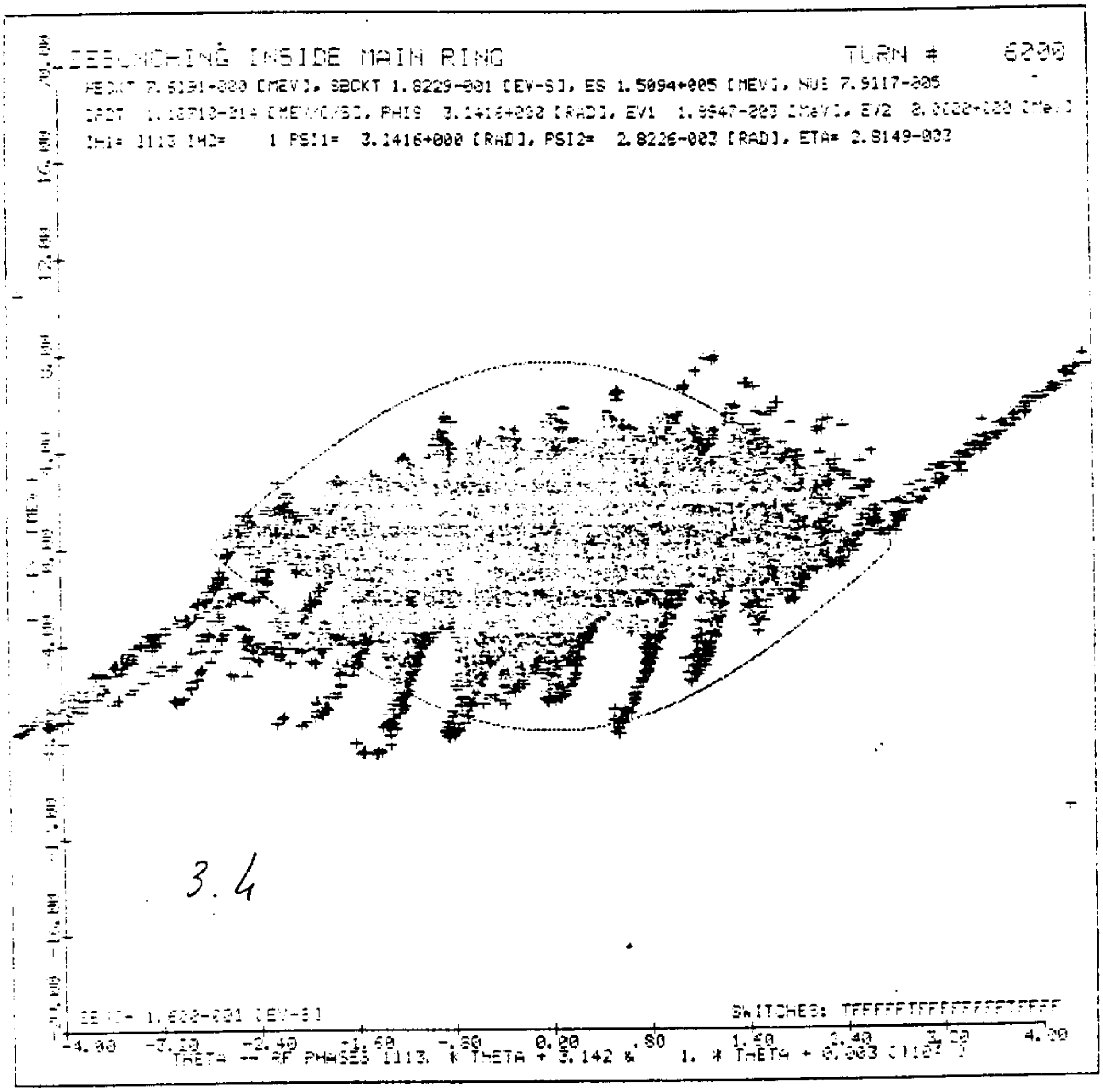
$N_p = 2 \cdot 10^{10}$ ppb.

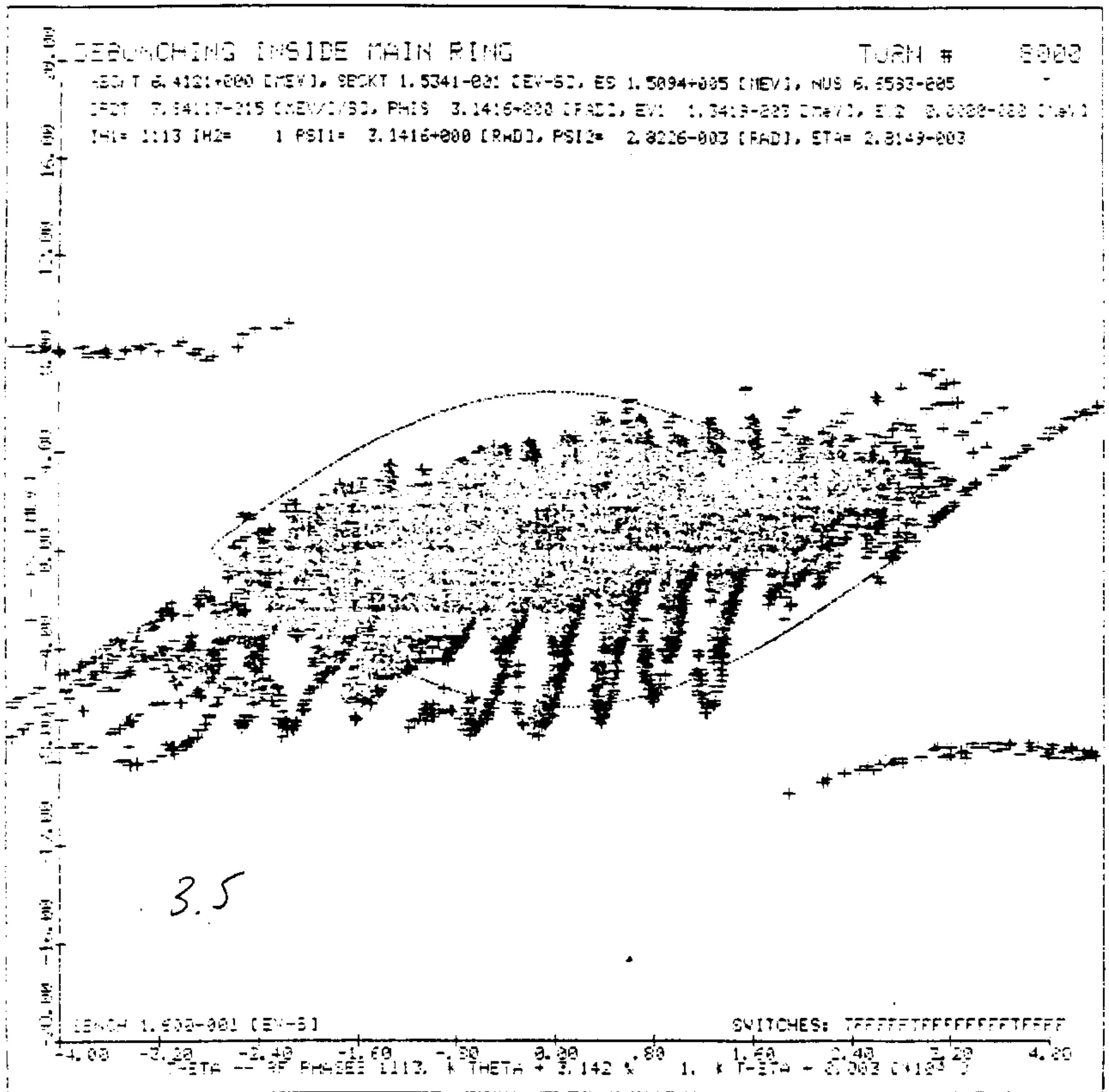



DEBUNCHING INSIDE MAIN RING
TURN # 2000
ES 1.5094+005 [MEV], NUS 1.2683-004
IH1= 1113 IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD], ETA= 2.8149-003
SWITCHES:
-4.00 -3.20 -2.40 -1.60 -.80 0.00 .80 1.60 2.40 3.20 4.00

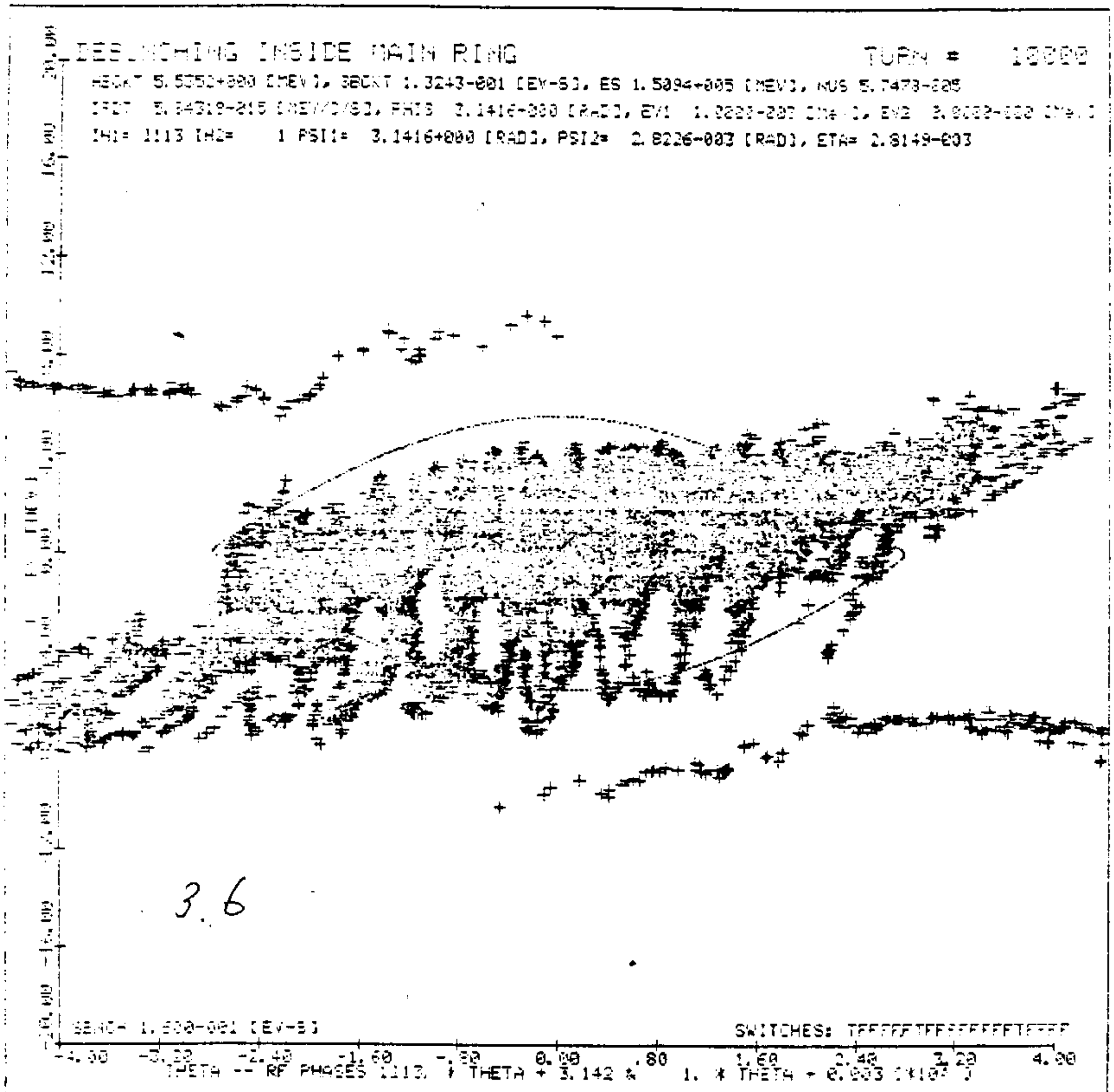
3.2


DEBUNCHING INSIDE MAIN RING
TURN # 4200
ES 1.5094+005 [MEV], NUS 5.7463-005
PSI2= 2.8026-003 [RAD], ETA= 2.8149-003
SWITCHES:
-4.00
0.00
4.00
3.3

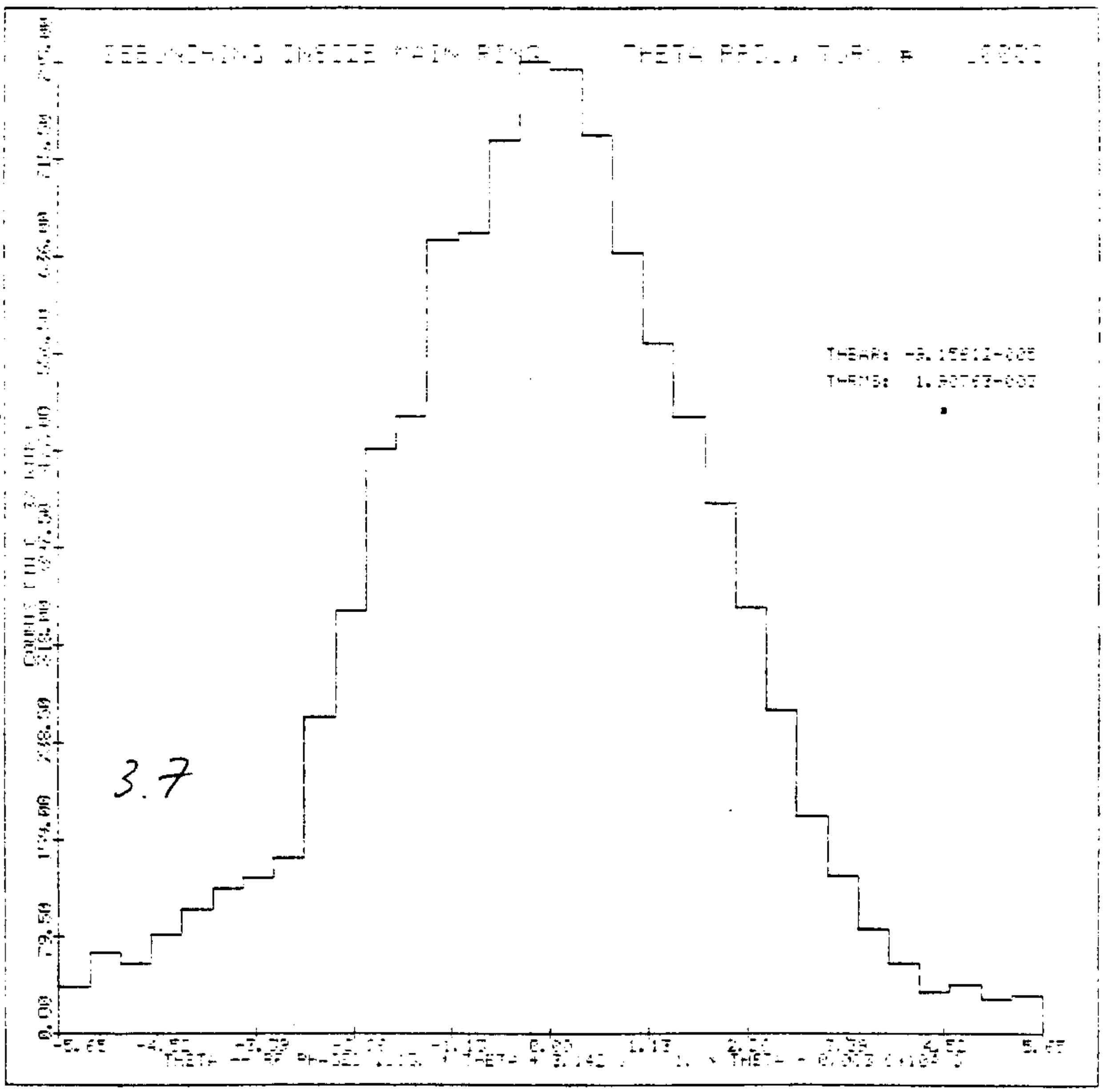

DEBUNCHING INSIDE MAIN RING
TURN # 6200
SBCKT 1.8229-001 [EV-S], ES 1.5094+005 [MEV], NUS 7.9117-005
PHIS 3.1416+000 [RAD], EV1 1.9947-003
IH1= 1113 IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD], ETA= 2.8149-003
SWITCHES: TFFFFTFFFFFFFFFTFFFF
-4.00
-3.20
-2.40
-1.60
-.80
0.00
.80
1.60
2.40
3.20
4.00
THETA -- RF PHASES 1113. * THETA + 3.142 & 1. * THETA + 0.003
3.4



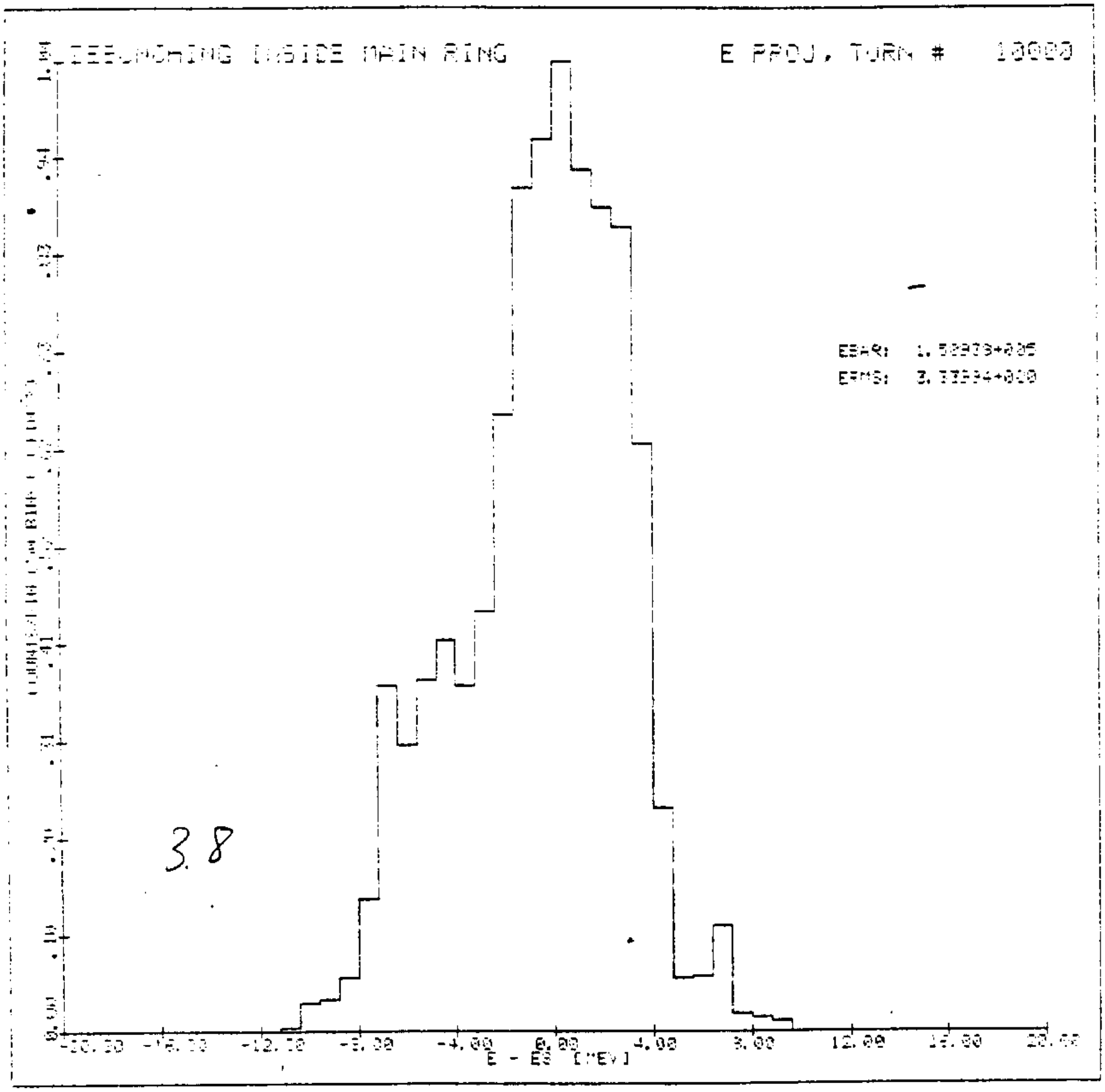
DEBUNCHING INSIDE MAIN RING
TURN # 8000
ES 1.5094+005 [MEV], NUS 6.5593-005
PHIS 3.1416+000 [RAD]
IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD]
SWITCHES:
-4.00 -3.20 -2.40 -1.60 -.80 0.00 .80 1.60 2.40 3.20 4.00
3.5



TURN = 10000
IH1= 1113 IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD], ETA= 2.8149-003
3.6
SWITCHES:
-4.00
-3.20
-2.40
-1.60
-.80
0.00
.80
1.60
2.40
3.20
4.00
THETA -- RF PHASES



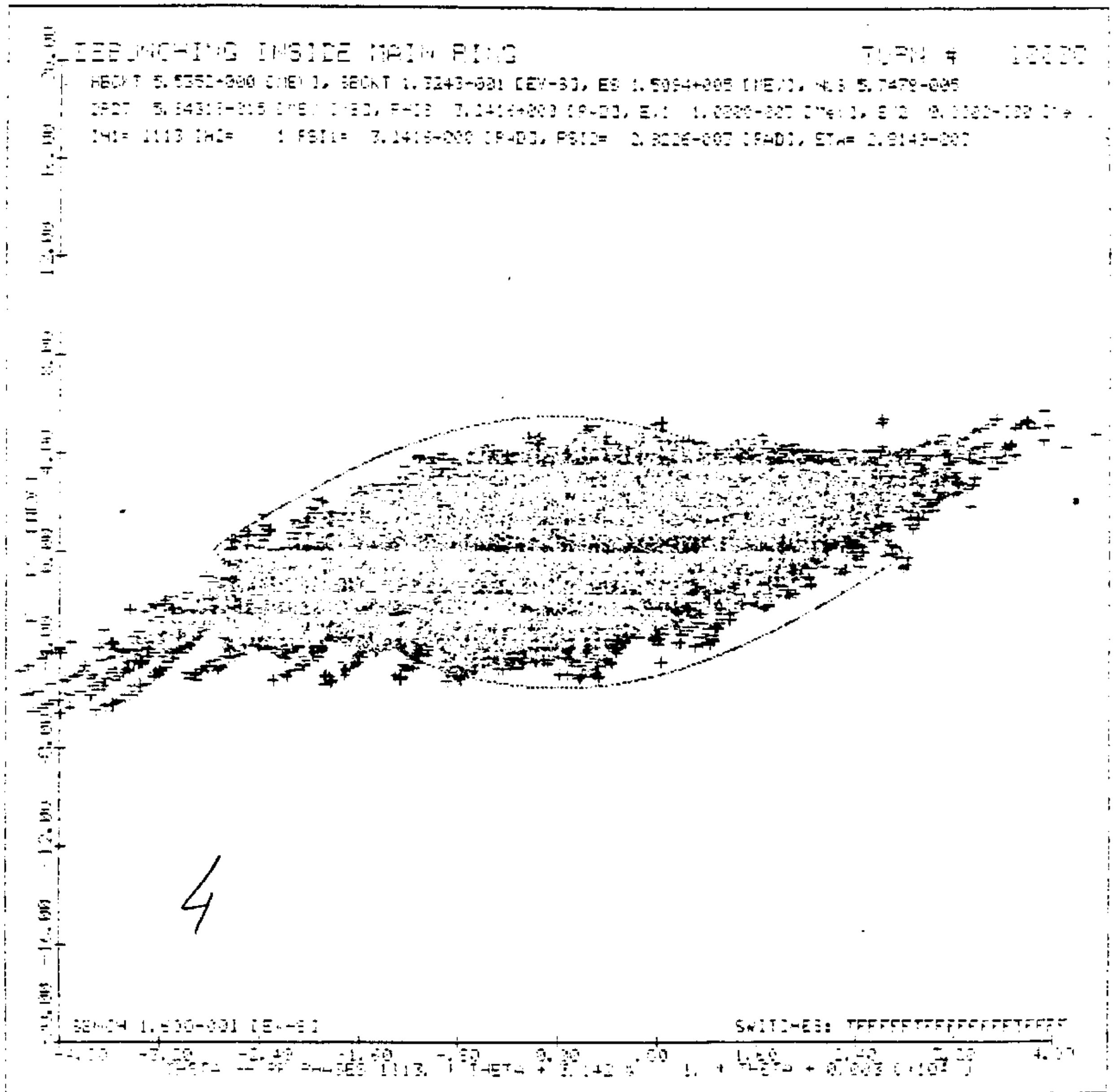
3.7


E PROJ, TURN # 10000
-4.00
0.00
4.00
8.00
12.00
E - ES [MEV]
3.8

Wide band Resonator $\begin{cases} f_{Res} = 2000 \text{ MHz} \\ Z(@ f_{Res}) = 800 \text{ k}\Omega \end{cases}$

$\Rightarrow \left|\frac{Z}{n}\right| = 19 \Omega.$

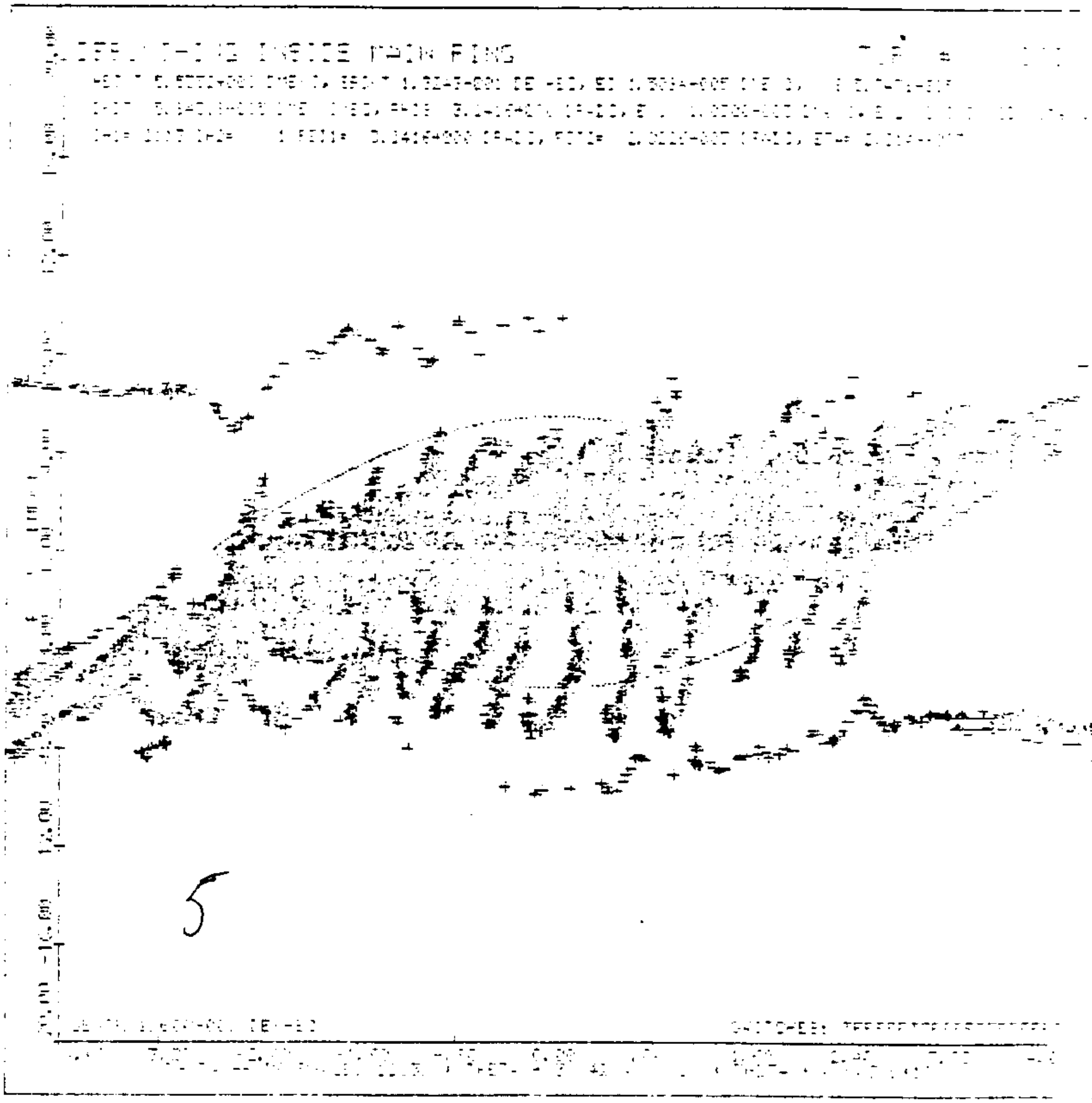
$N_p = 5 \cdot 10^9$ ppb.



Wide band resonator $\begin{cases} f_{res} = 2000\ \text{MHz} \\ Z(@ f_{res}) = 800\ \text{k}\Omega \end{cases}$

$$\Rightarrow \left|\frac{Z}{n}\right| \simeq 19\ \Omega$$

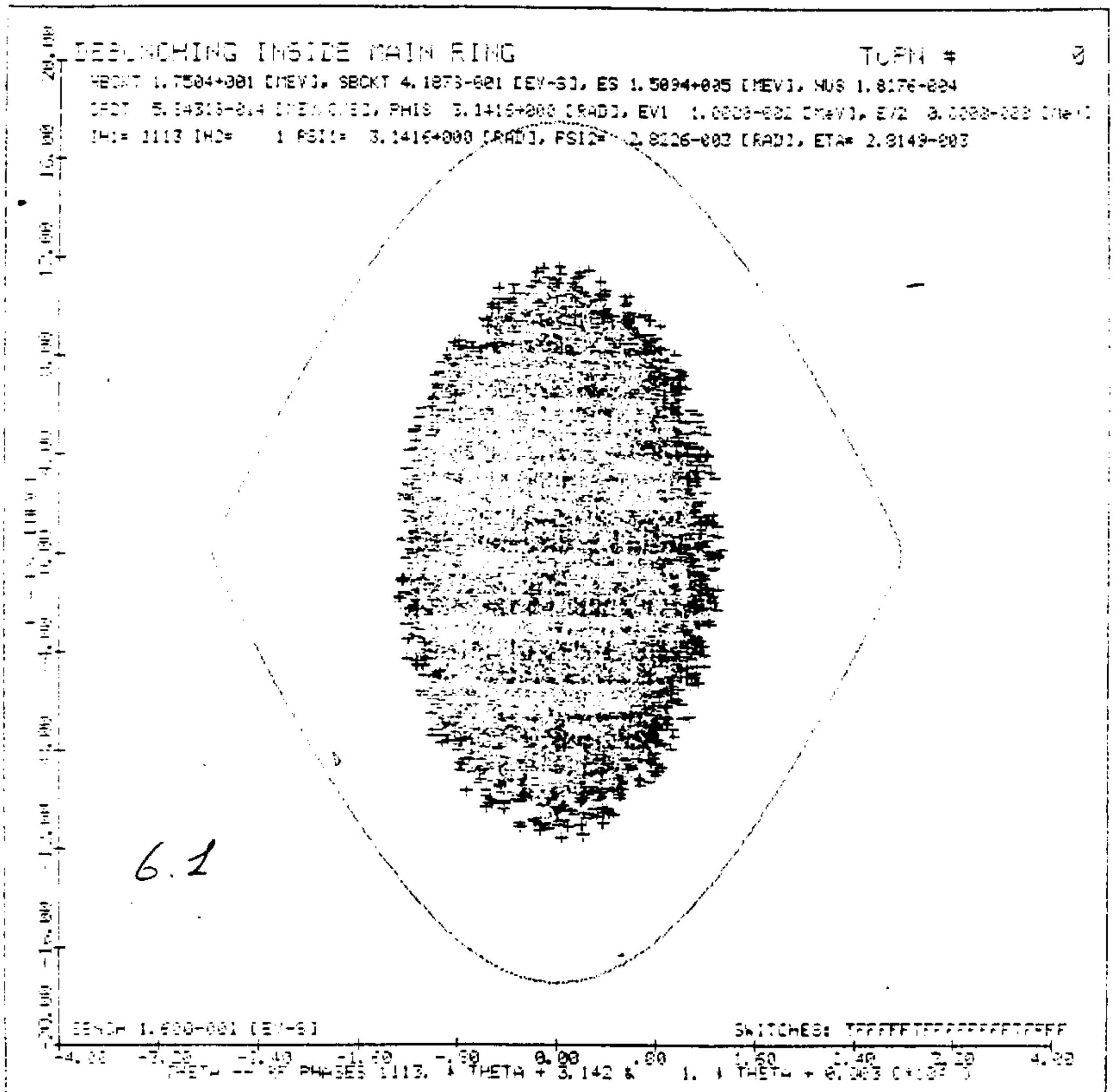
$N_p = 10^{10}$ ppb.

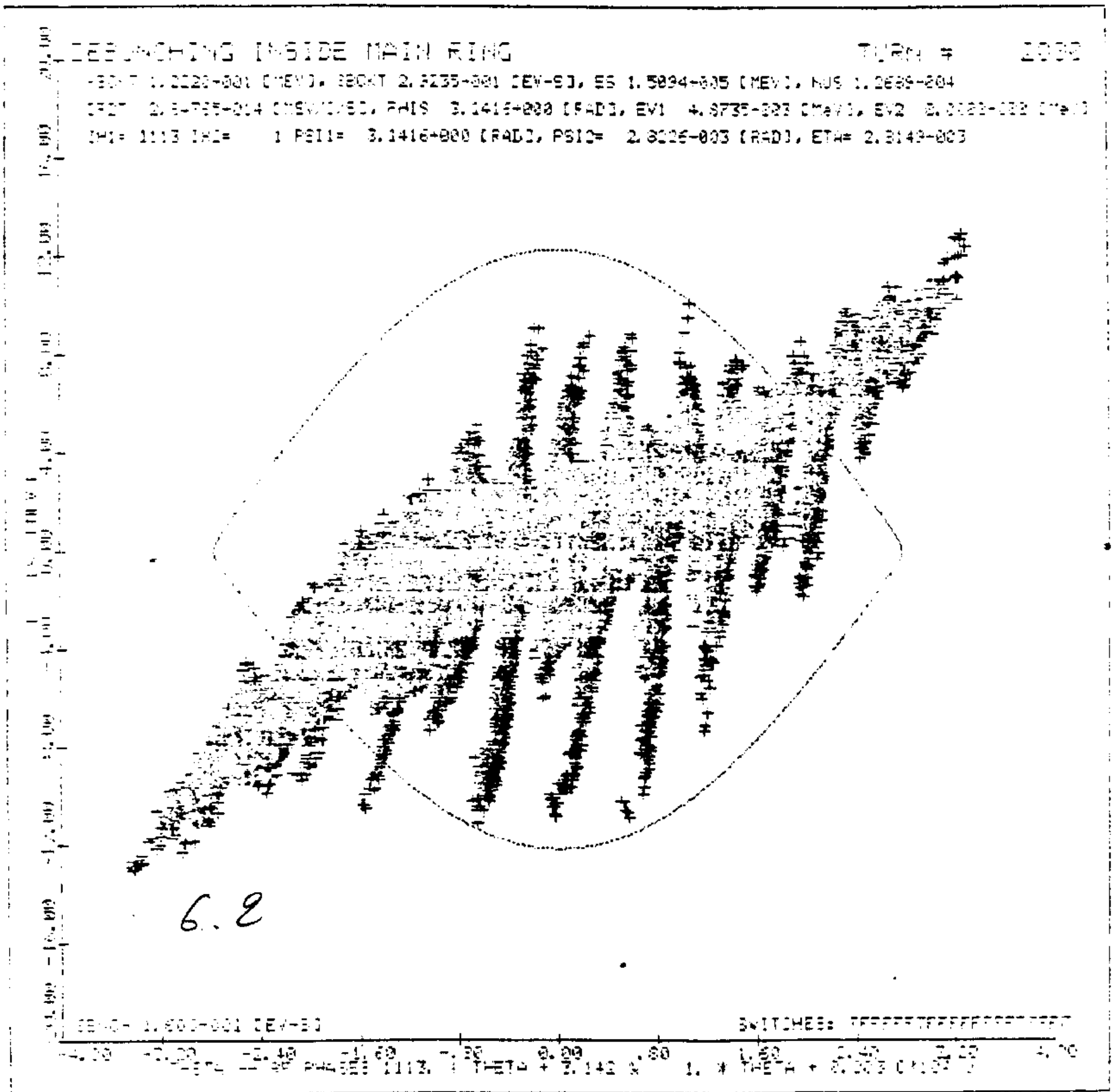


Wide band resonator $\begin{cases} f_{Res} = 2000\ MHz \\ Z(@f_{Res}) = 800\,k\Omega \end{cases}$

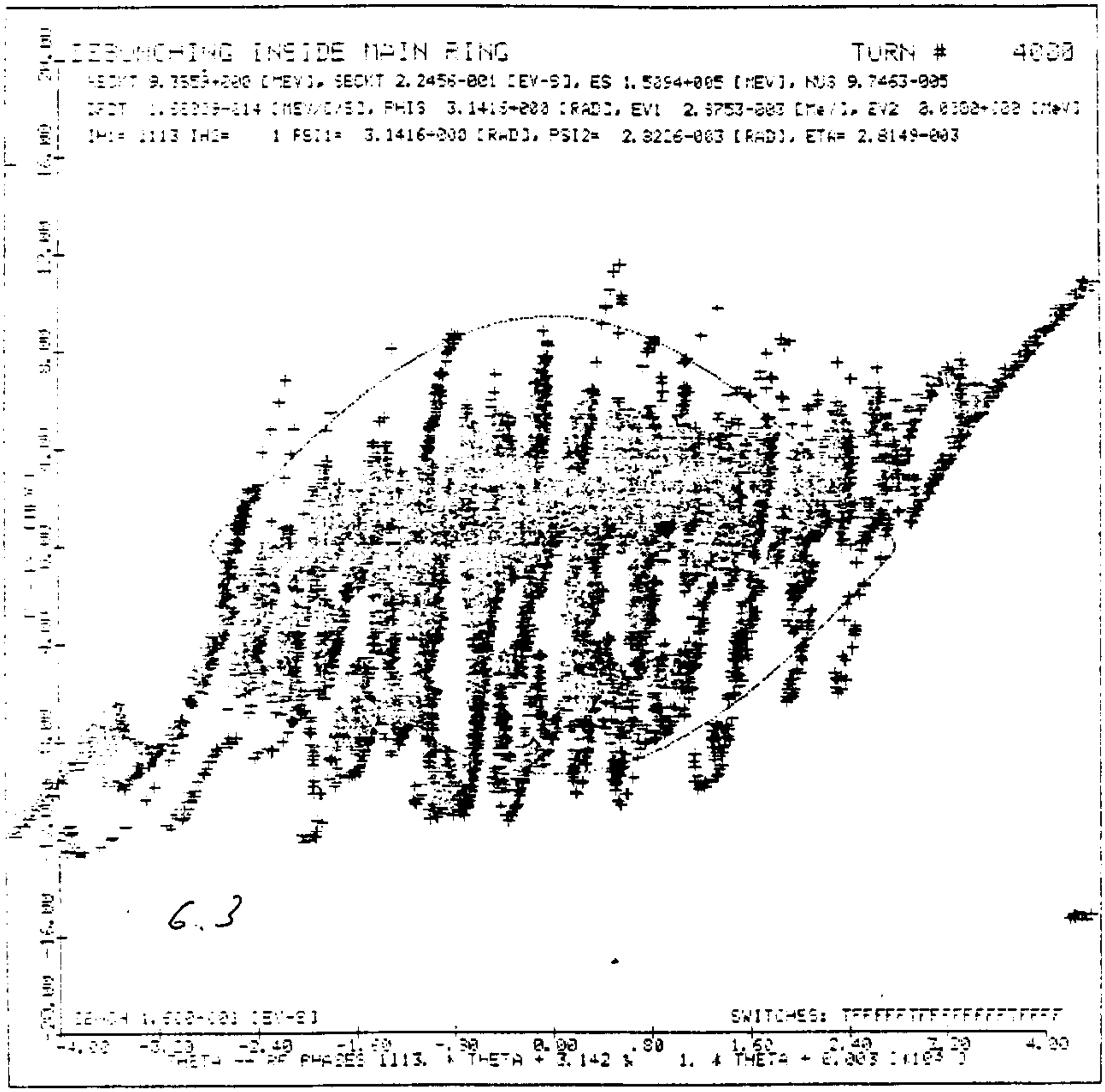
$$\Rightarrow \frac{Z}{n} = 19.1\,\Omega$$

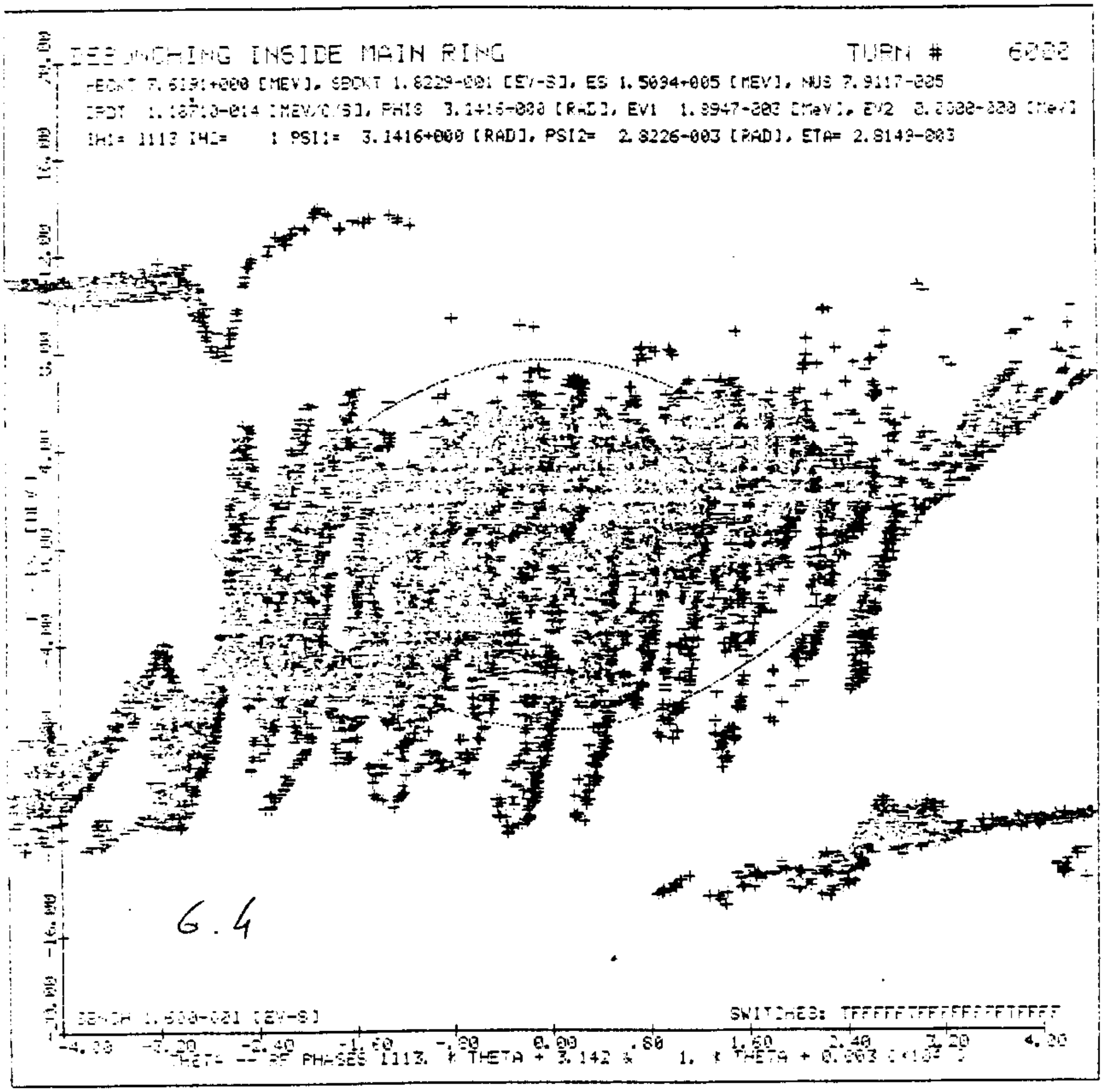
$N_p = 2.10^{10}$ ppb



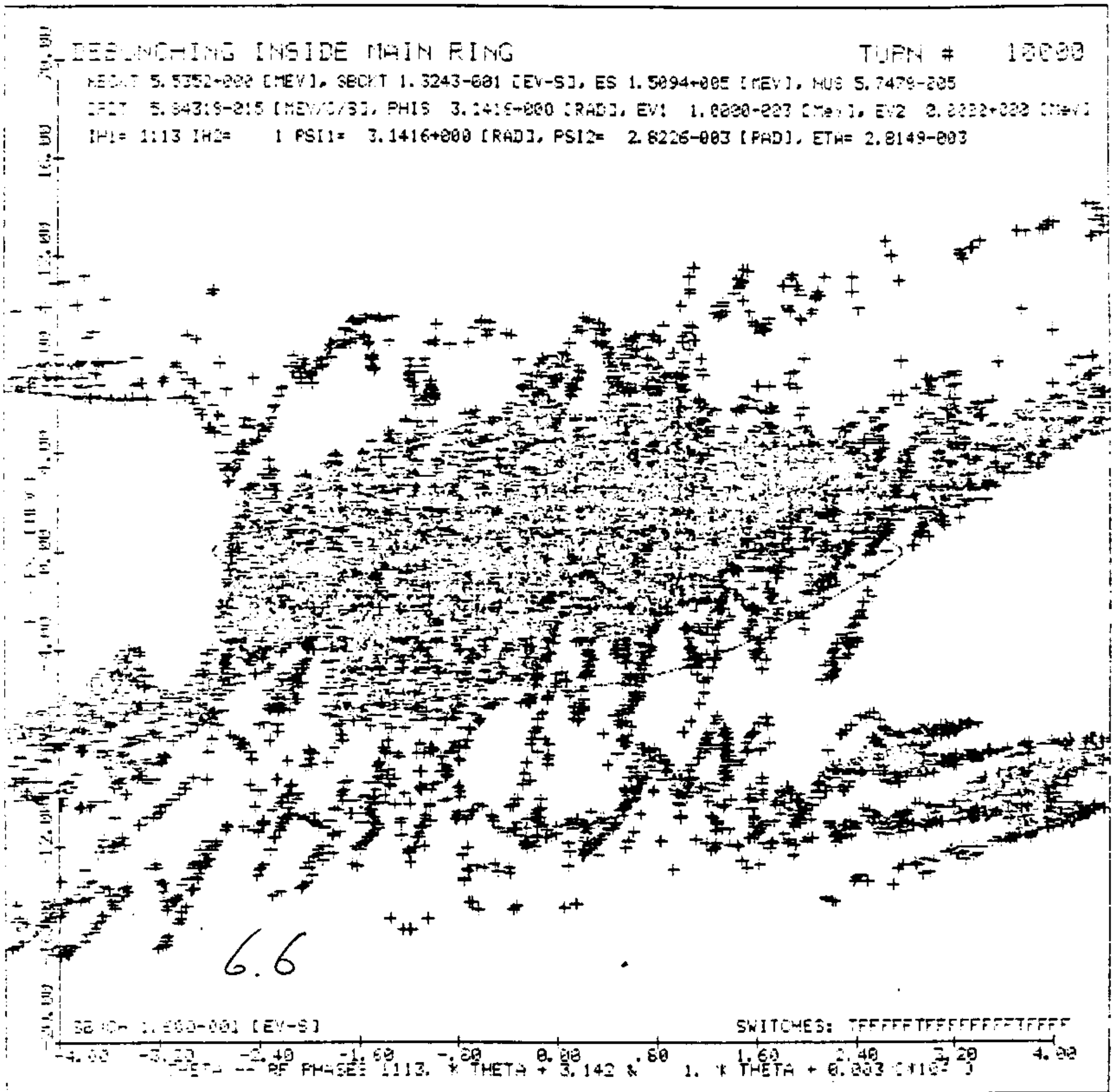


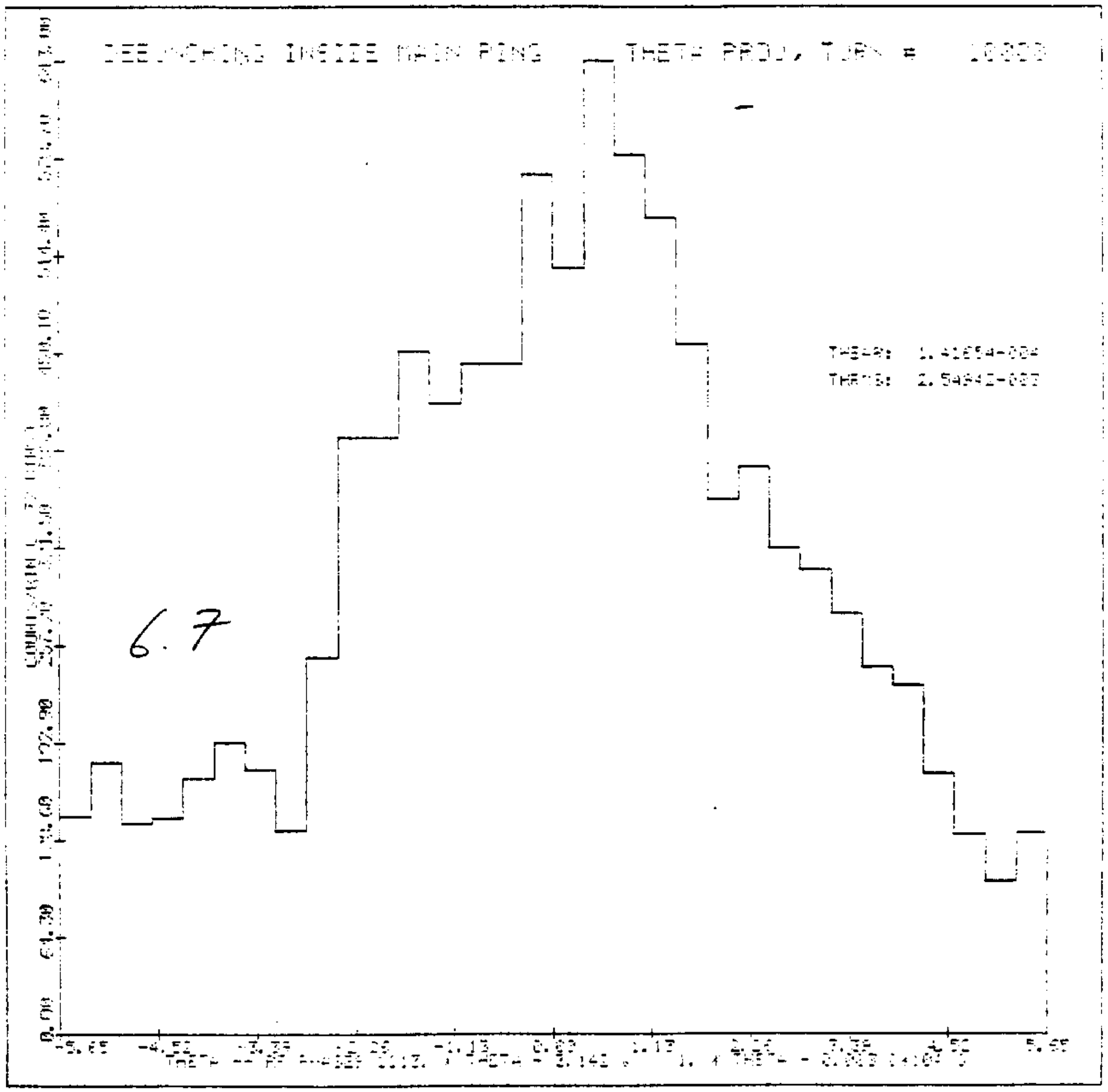
DEBUNCHING INSIDE MAIN RING
TURN #
ES 1.5094+005 [MEV]
PHIS 3.1416+000 [RAD], EV1
PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD], ETA= 2.3149-003
SWITCHES:
0.00
THETA
6.2

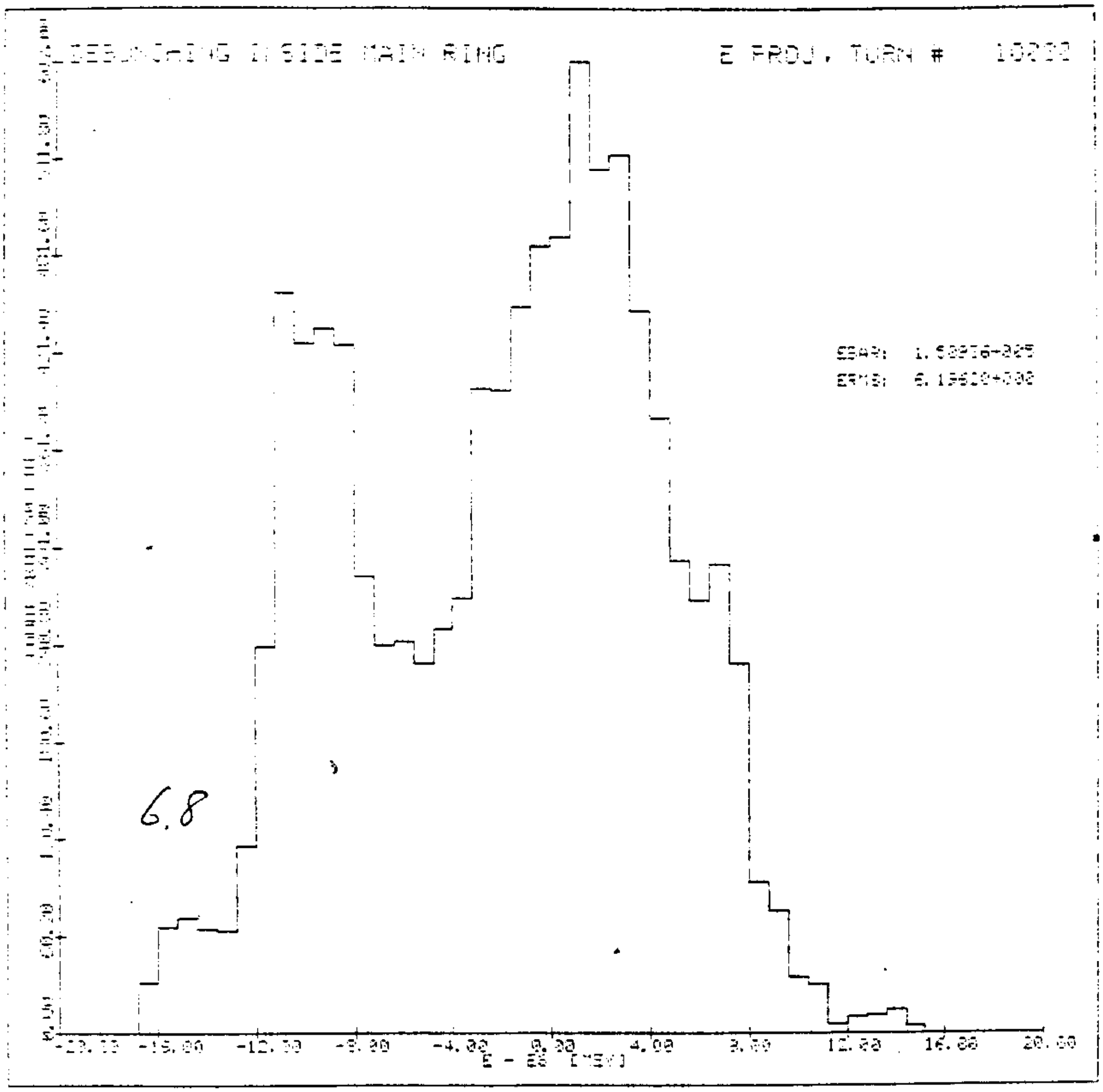

DEBUNCHING INSIDE MAIN RING
TURN # 4000
SECKT 2.2456-001 [EV-S], ES 1.5894+005 [MEV], NUS 9.7463-005
PHIS 3.1416+000 [RAD], EV1 2.8753-003
1 PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD], ETA= 2.8149-003
SWITCHES:
THETA
6.3


INSIDE MAIN RING
TURN # 6000
ES 1.5094+005 [MEV], NUS 7.9117-005
PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD], ETA= 2.8149-003
SWITCHES:
-4.00
-2.40
-1.60
0.00
.80
1.60
2.40
4.00
PHASES 1113.
6.4


TURN #
IH1= 1113 IH2= 1 PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD], ETA= 2.8149-003
-4.00 -3.20 -2.40 -1.60 -.80 0.00 .80 1.60 2.40 3.20 4.00
6.5

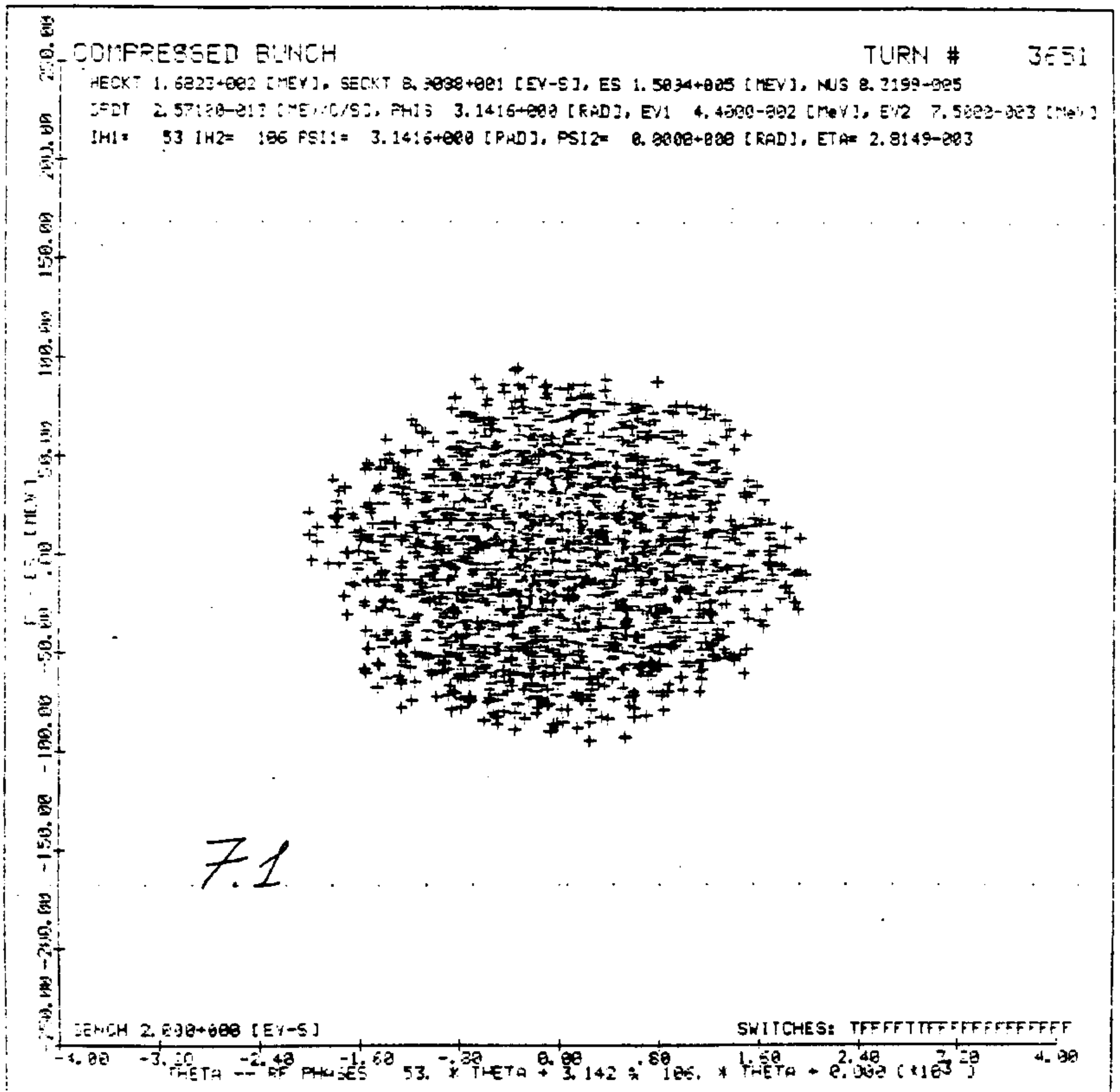

DEBUNCHING INSIDE MAIN RING
TURN #
SBCKT 1.3243-001 [EV-S], ES 1.5094+005 [MEV]
PHIS
1 PSI1= 3.1416+000 [RAD], PSI2= 2.8226-003 [RAD], ETA= 2.8149-003
6.6
SWITCHES:
-2.40
0.00
.80
1.60
2.40
4.00
RF PHASES 1113. * THETA + 3.142 & 1. * THETA + 0.003


6.7
-5.65
-4.52
0.00
1.13
4.52
5.65

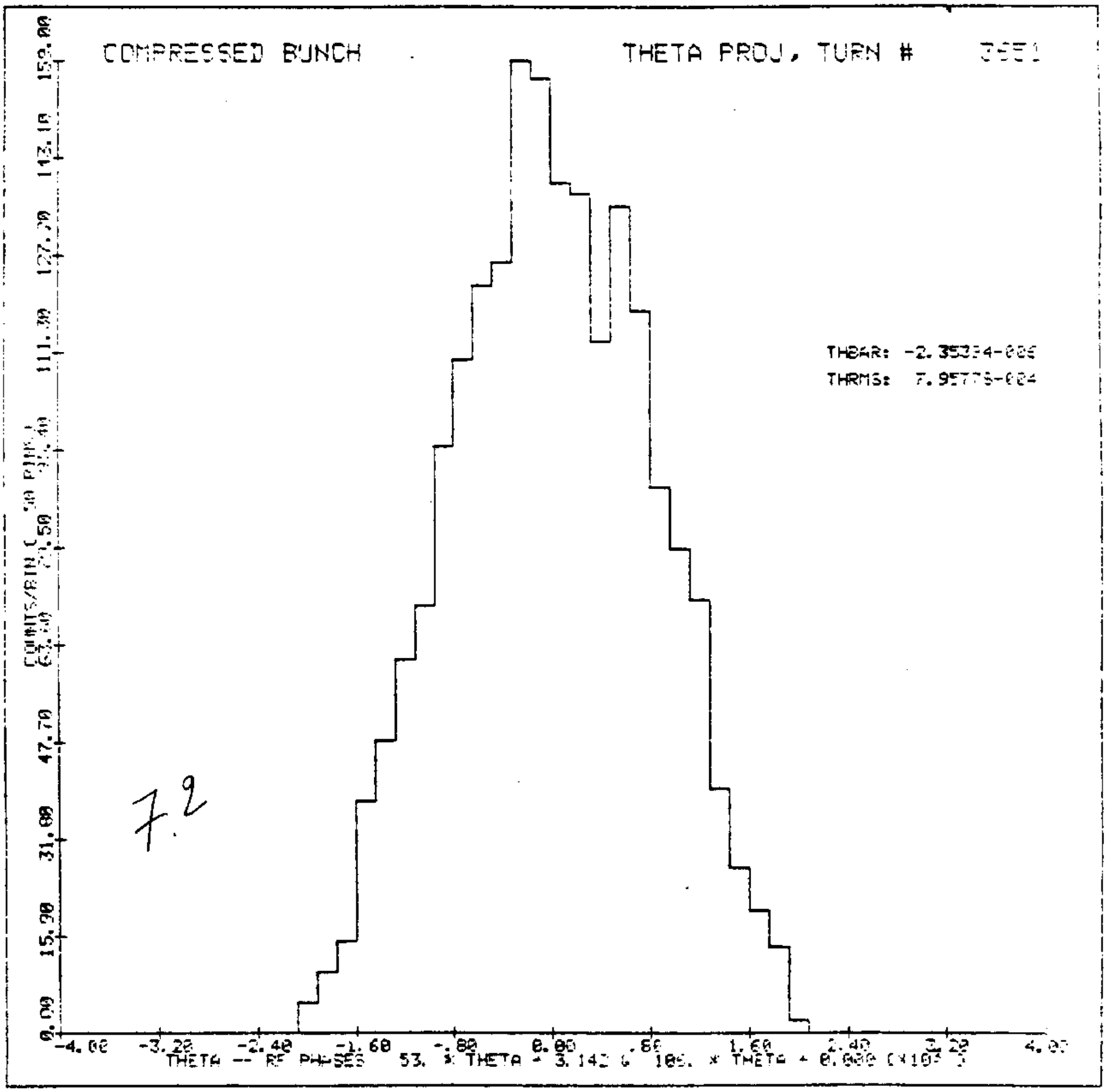

E PROJ, TURN #
6.8
-4.00
0.00
4.00
12.00
16.00
20.00

Bunch rotation

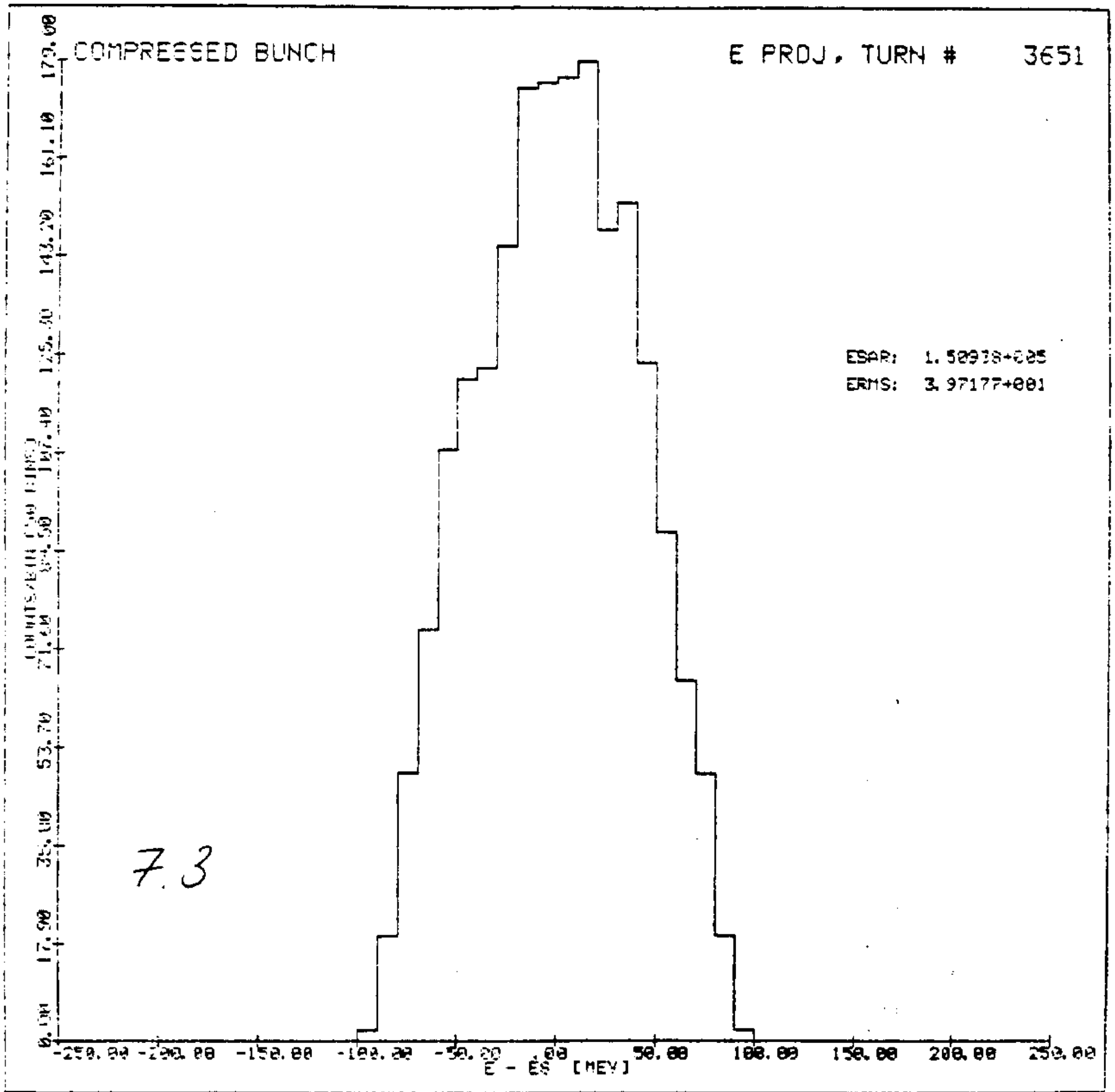
$|Z/n| = 0\ \Omega$.



7.1



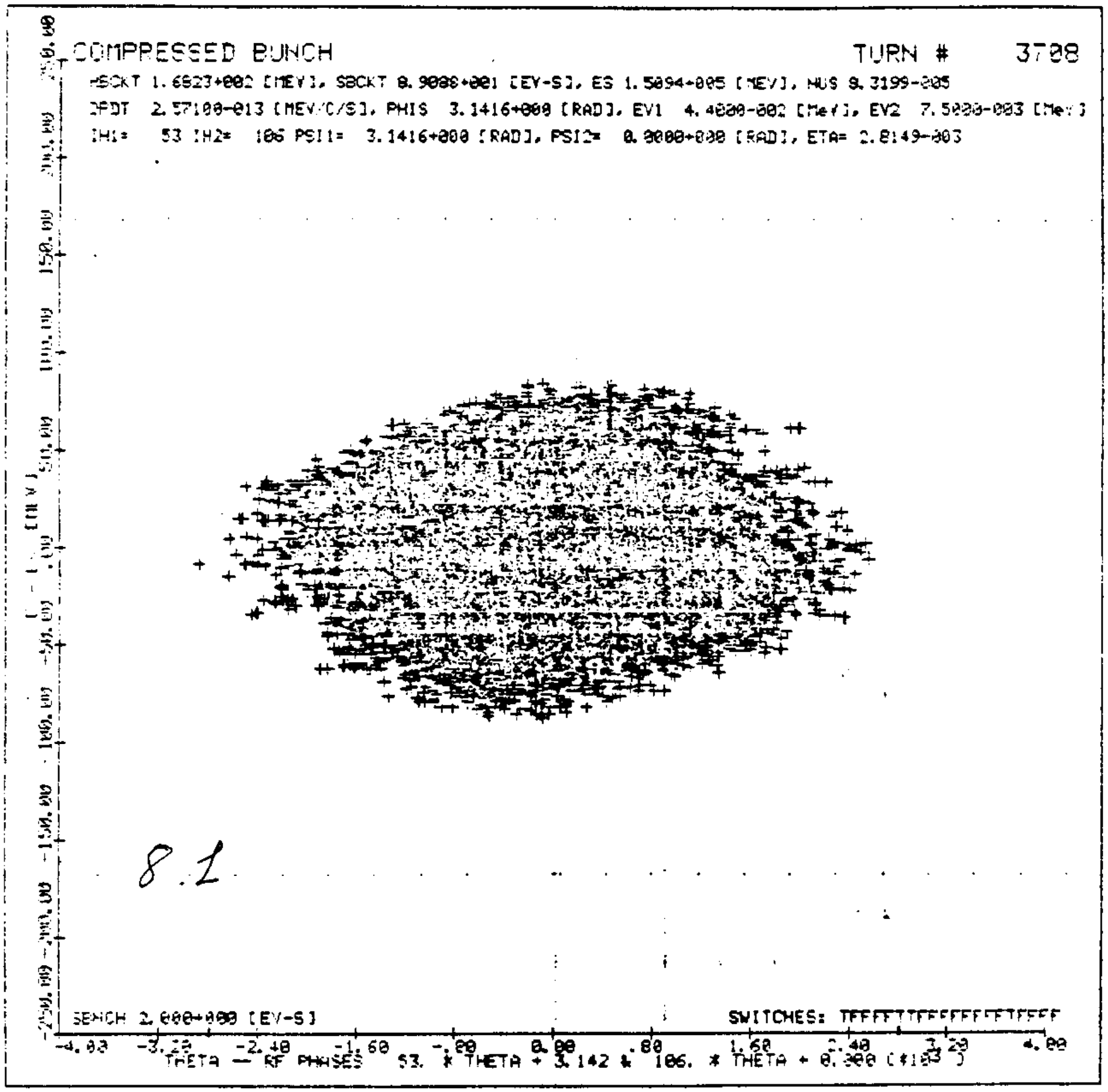
COMPRESSED BUNCH
THETA PROJ, TURN # 3551
THBAR: -2.35334-006
THRMS: 7.95775-004
COUNTS/BIN (30 BINS)
0.00
15.90
31.80
47.70
63.60
79.50
95.40
111.30
127.20
143.10
159.00
-4.00
-3.20
-2.40
-1.60
-.80
0.00
.80
1.60
2.40
3.20
4.00
THETA -- RF PHASES 53. * THETA + 3.142 & 106. * THETA + 0.000 (X10^-3)
7.2

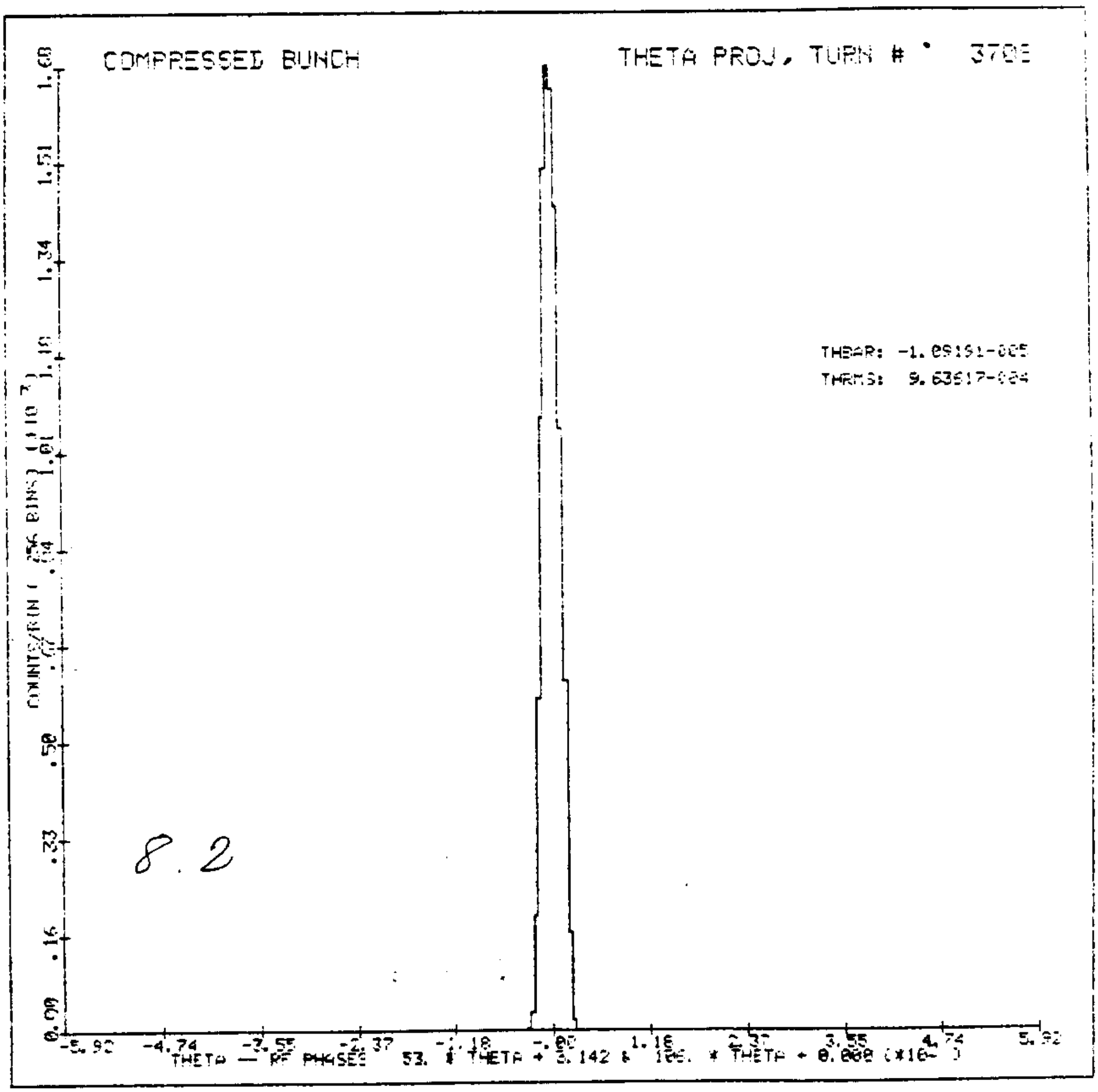

COMPRESSED BUNCH
E PROJ, TURN # 3651
ESAR: 1.50938+005
ERMS: 3.97177+001
COUNTS/BIN
E - ES [MEV]
7.3

Bunch rotation.

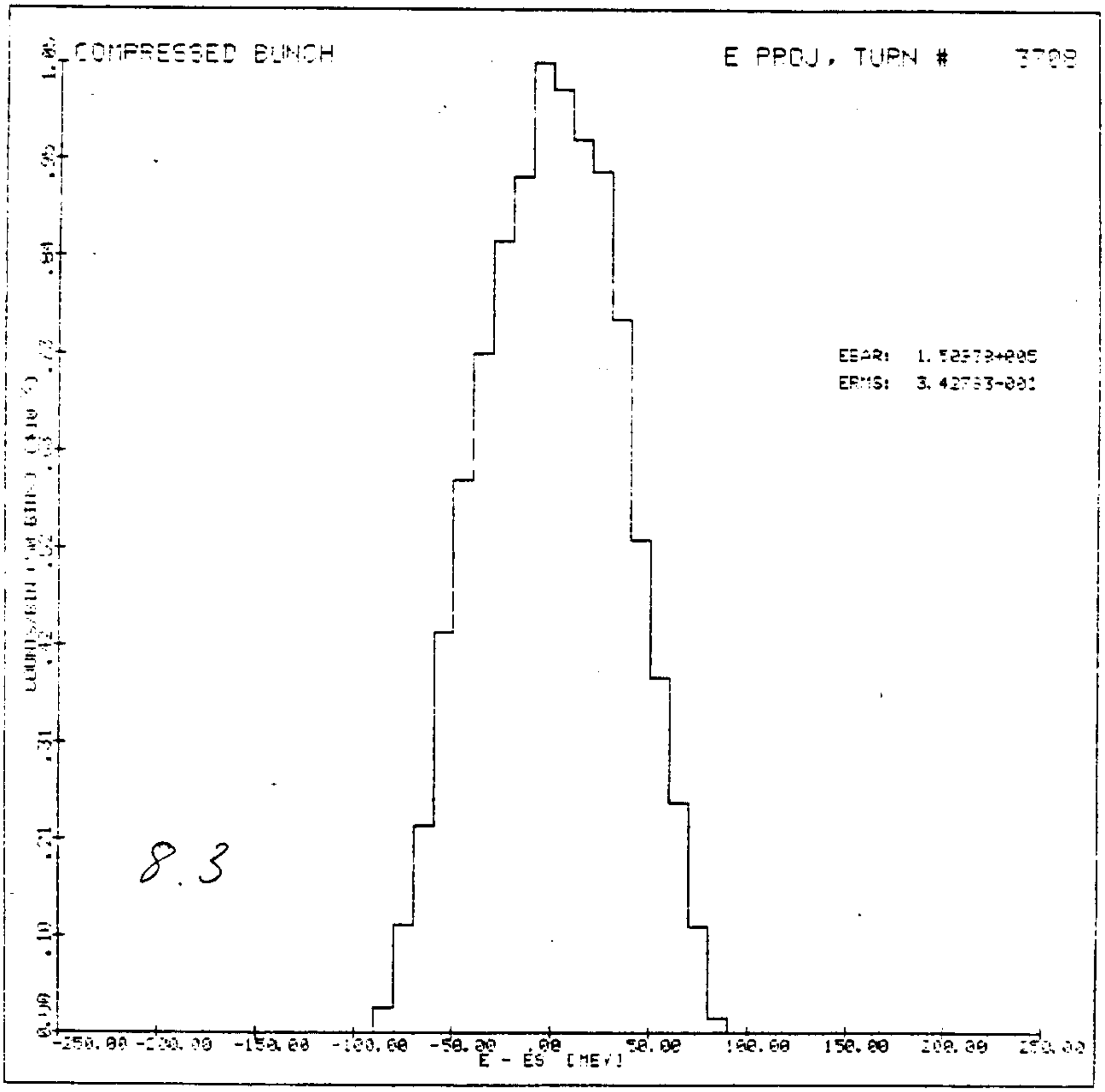
$\left|\frac{Z}{n}\right| = 19\Omega$

$N_b = 2.10^{11}$ p/b.





COMPRESSED BUNCH
THETA PROJ, TURN # 3700
THBAR: -1.09191-005
THRMS: 9.63917-004
COUNTS/BIN (256 BINS) (X10 3)
0.00
.16
.33
.50
.67
.84
1.01
1.18
1.34
1.51
1.68
-5.92
-4.74
-3.55
-2.37
-1.18
-.00
1.18
2.37
3.55
4.74
5.92
THETA — RF PHASES 53. * THETA + 3.142 & 106. * THETA + 0.000 (*10-)
8.2



COMPRESSED BUNCH
E PROJ, TURN #
ESAR:
ERMS:
-250.00
-200.00
-150.00
-100.00
-50.00
.00
50.00
100.00
150.00
200.00
E - ES [MEV]

8.3

Fermilab

TM-1495-Rev.
0439.030

SIMULATION OF BUNCHES COALESING IN THE MAIN RING, IN THE PRESENCE OF A HIGH-FREQUENCY, WIDE-BAND RESONATOR

R. Garoby
December 4, 1986

INTRODUCTION

During the first part of the coalescing process, bunches are being stretched until they fill the ≃1 kV @ 53 MHz bucket.

Applying the "Keil-Schnell-Boussard" criteria (see Appendix A) for microwave instability inside that bunch gives:

$$|Z/n| \leq 5.6\ \Omega \text{ for } N_b = 10^{10} \text{ ppb} .$$

It is very likely that local instabilities develop inside the bunch during the manipulation. The computer program ESME was run under these conditions to give an approximate picture of the bunch distortions. Outputs are presented here.

Since microwave signals had been observed during the second part of coalescing (bunch rotation), some simulations have been done at that part. No catastrophic degradation showed up with the model used, as the computer outputs indicate.

THE MODEL

The high frequency impedance seen by the beam was simulated by a Q=1 resonator at 2000 MHz. Two "reasonable" impedance values were tested.

Z (@ 2000 MHz) = 800 kΩ equivalent to $|Z/n| = 19\ \Omega$ and
Z (@ 2000 MHz) = 400 kΩ equivalent to $|Z/n| = 9.5\ \Omega$.

Care was taken that the program was giving meaningful results. That was checked by comparing the voltage due to the resonator, along the bunch, as computed by ESME, with the one given by approximate formulas (@ CERN 77-10, p. 95). Unfortunately such a formula can only be used when the bunch shape is smooth, so only the initial state has been analyzed. A satisfying set of parameters is: 10,000 macroparticles into 32 FFT bins, for debunching analysis. CPU time is already greater than four hours in the FPS 164 in these conditions.

For bunch rotation analysis, the number of FFT bins was brought up to 256. It was necessary, since bunch length varies drastically. Ten thousand (10,000) macro-particles were also used. Reliability of the results is probably less good than for debunching. But since little bunch distortions are detected up to $N_b = 2\times10^{11}$ ppb (2x design value), one can safely consider that an upper limit of the bunch degradation is obtained.

DEBUNCHING SIMULATIONS RESULTS

Figures 1.1, 1.2, and 1.3 show the voltage program used, together with bucket height and ν_s. The table below indicates the parameters used in the simulation together with the relevant output pictures.

$\|Z/n\|$	0.1 Ω	9.5 Ω	19 Ω	19 Ω	19 Ω
N_b		2×10^{10} ppb	5×10^{9}	10^{10}	2×10^{10}
Figures	2.1 to 2.8	3.1 to 3.8	4	5	6.1 to 6.8

Figure 4 shows the present operational situation (at least if one guesses $|Z/n| = 19$ Ω!).

The result is already different from the zero intensity one (Fig. 2.6). Bunch distortion is not excessive, but energy spread is obviously greater by 2 or 3 MeV. This could explain the need to go to a higher voltage during bunch rotation (33 kV @ h = 53 raised to 44 kV) since bunch rotation basically exchanges energy spread for bunch length.

The situation at $N_b = 10^{10}$ ppb with $|Z/n| = 19$ Ω is very bad (Fig. 5), and at $N_b = 2\times10^{10}$ ppb (Fig. 6.6) it is hard to describe.

If one guesses $|Z/n| = 9.5$ Ω, the result (Fig. 3.6) is comparable to $|Z/n| = 19$ Ω (Fig. 5) but at two times the intensity.

BUNCH ROTATION RESULTS

Because of program capabilities the simulation was run on a single-bunch with $\epsilon_\ell = 2$ eV-sec, initialy matched to a 200 V h = 53 bucket. That was supposed to be an approximation of the chain of 10 adjacent bunches. RF parameters during rotation are the ones previously used by D. Wildman:

$$\hat{V}(h = 53) = 44 \text{ kV}$$

$$\hat{V}(h = 106) = 7.5 \text{ kV}.$$

The low intensity limit is described in Figs. 7.1, 7.2, and 7.3.

Computations have been done for $|Z/n| = 19$ Ω and $N_b = 2\times10^{11}$ ppb (2x design value). Outputs are shown in Fig. 8.1, 8.2, and 8.3.

The following table summarizes the comparison of some relevant numbers in both cases.

	N_b = 0 ppb	$N_b = 2\times10^{11}$ ppb
Optimum rotation time	3651 turns	3708 turns
RMS spread in azimuth	7.96×10^{-4} rad	9.64×10^{-4} rad
RMS energy spread	39.7 MeV	34.3 MeV

So the minimum length is observed later (57 turns or more than 1 msec) and bunch length is increased by ≃20%. Computation at $N_b = 10^{11}$ ppb indicate only an increase of ≃6%. No noticeable bunch distortions show up.

This part of the process is much less sensitive to the microwave wide-band resonator than the first one.

CONCLUSIONS

With due regard to the crude models used for the computations, one can nevertheless estimate that:

1. The first part of the coalescing process is very sensitive to the machine impedance. Great difficulties are likely to appear when going to the design intensity, or slightly higher.

2. The bunch rotation is much more tolerant, but some decrease in performance can be suspected, with a threshold around the design intensity ($N_b = 10^{11}$ ppp).

The obvious recommendations that one can make from that basis are:

1. Measure machine impedance and try to reduce it.

2. Modify the first part of the coalescing process to make it less impedance sensitive. One possibility for that is to go to a more adiabatic bunch lengthening technique, which will provide a stretched bunch in a much shorter amount of time.